This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

+ *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.

+ *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.

+ *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.

+ *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at `http://books.google.com/`

3 3433 06273212 2

PWE

Bayley

MINERALS AND ROCKS

MINERALS AND ROCKS

THE ELEMENTS OF MINERALOGY AND LITHOLOGY

FOR THE USE OF

STUDENTS IN GENERAL GEOLOGY

BY

WILLIAM SHIRLEY BAYLEY, PH.D.

PROFESSOR OF GEOLOGY IN THE UNIVERSITY OF ILLINOIS

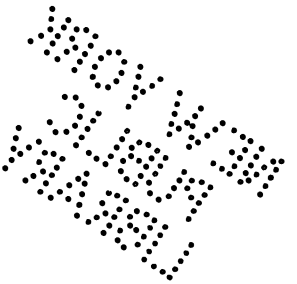
NEW YORK AND LONDON

D. APPLETON AND COMPANY

1915

THE NEW YORK
PUBLIC LIBRARY
ASTOR, LENOX AND
TILDEN FOUNDATIONS
R 1915 L

COPYRIGHT, 1915, BY
D. APPLETON AND COMPANY



Printed in the United States of America

PREFACE

THIS brief description of the most important minerals and rocks is intended for the use of students in geology who wish some familiarity with the material of the earth's crust, but who may not find the time for courses in mineralogy and lithology. It was written in the hope that it might serve a useful purpose as a laboratory guide. The minerals and rocks chosen for description are those which are most frequently met with and, in addition, those which, though uncommon, are for some reason of special interest.

Only so much of the description of each mineral is given as is essential to its recognition. All unessential details are omitted. For occurrence and crystallization more complete treatises must be consulted.

On the other hand, the blowpipe tests are given fully in order that the student in the field may be able to recognize the chemical constituents of minerals with which he may not be familiar.

The discussion of rocks is intended to be mainly suggestive. It is believed that it is of much more value to the student to understand the significance of his rock specimens than to be able to identify them by name. Only the commonest rock names are defined. The rock groups are emphasized.

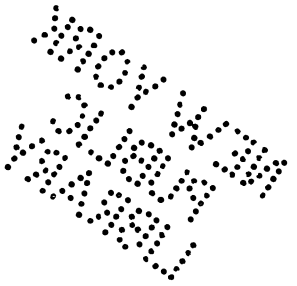
The "Keys" for the determination of minerals and rocks are merely guides to the descriptions in the body of the text.

The author wishes to acknowledge his indebtedness to Dana's Text Book of Mineralogy and Moses and Parson's Mineralogy for many of the crystal illustrations which appear in this volume. His thanks are due to Mr. C. S. Ross,

assistant in geology at the University of Illinois, for most of the photographs from which the half-tones were made.

WILLIAM SHIRLEY BAYLEY.

URBANA, ILL., *July* 5, 1915.



CONTENTS

I. MINERALS

	PAGE
I. Introduction	1
II. Description of Minerals	7
Elements	7
Sulphides	12
Arsenides and Sulph-Arsenides	22
Sulph-Arsenites and Sulph-Antimonites	25
Chlorides and Fluorides	27
Nitrates	31
Borates	31
Oxides	33
Hydroxides	42
Aluminates, Ferrites and Chromites	46
Carbonates	49
Normal Carbonates	49
Basic Carbonates	59
Sulphates	60
Anhydrous Sulphates	60
Hydrated Sulphates	64
Tungstates, Molybdates and Chromates	66
Phosphates, Arsenates and Vanadates	70
Apatite Group	70
Hydrated Phosphates and Arsenates	74
Columbates and Tantalates	77
Uranyl Compounds	80
Silicates	82
Anhydrous Silicates	83
Pyroxenes and Amphiboles	106
Feldspars	112
Hydrated Silicates	119
Zeolites	121
Titanates and Titano-Silicates	125

PAGE

III. Determination of Minerals with the Aid of the Blowpipe 128
IV. Characteristic Reactions of the More Important Elements and Acid Radicals 151
V. Key to the Determination of Minerals . . . 168
VI. List of Minerals Arranged According to Their Important Constituents 181

II. ROCKS

I. Synopsis of a Classification of Rocks . . . 189
Crystalline Rocks 190
Fragmental Rocks 200
Other Rocks 206
II. Key to the Determination of Rocks (except Coal). 207
Index 219

MINERALS AND ROCKS

MINERALS AND ROCKS

I

INTRODUCTION

THE solid portion of the earth's surface consists of rocks which are composed either of minerals (granite), or of the hard parts of animals (shell limestone) or plants, or of their decomposition products (coal), or of mixtures of organic and inorganic matter (many limestones). The rocks form the earth's crust in the same way that floors, walls, etc., form a building. They are architectural units. The materials constituting the rocks may be likened to the bricks of the walls or to the boards of the floors. Most rocks are composed of minerals or of mixtures of mineral and organic matter. Moreover, much of the matter of organic origin has the same composition as some of the mineral matter; consequently, a knowledge of minerals is essential before the character of the rocks can be properly appreciated. Further, many of the minerals occurring in the earth's crust are of great economic importance, because from them we obtain the metals, and make sulphuric acid, glass and many other substances that enter so largely into the life of civilized beings. Although some 1,200 different mineral substances have been assigned names, only a

comparatively few of these are important, either as constituents of rocks, or as sources of materials useful to man.

Minerals.—A mineral is an inorganic, natural compound that occurs in the earth's crust. Most minerals are definite chemical compounds, but some are mixtures of several compounds and others are solid solutions of several substances in one another. Whether a definite compound or a mixture, every mineral is characterized by individual properties and usually by distinct forms (crystals), and by these properties we recognize them.

Chemically, minerals are elements, sulphides, oxides, hydroxides or the salts of various acids. Most of the common ones are anhydrous, but a few, apparently, consist of salts combined with water, thus: gypsum $= CaSO_4 + 2H_2O$.

Determination of Minerals.—Some minerals are so plainly characterized that they may be recognized at a glance. Many others may be determined by the application of a few simple physical tests. A few require the application of chemical tests before their true nature may be appreciated. The chemical tests that can be applied most conveniently are those based on reactions with dry reagents at high temperatures. Because high temperatures are most readily obtained by the aid of a blowpipe, reactions of this kind are known as blowpipe reactions, and the tests applied are designated blowpipe tests.

Physical Properties.—The physical properties of most value in diagnosis are: Form, color, streak, luster, hardness, tenacity, and specific gravity or density.

Form.—Substances passing from the fluid to the solid state usually assume certain definite forms that are characteristic. These substances, if not prevented from doing so by external conditions, bound themselves by plane surfaces according to certain definite arrangements. A body so bounded is a *crystal*, and the process of forming crystals is *crystallization*.

Crystals are divisible into six groups, or systems, known as isometric, hexagonal, tetragonal, orthorhombic, monoclinic and triclinic, in accordance with the symmetry exhibited by the arrangement of their faces. The systematic study of such forms is known as crystallography. In many cases the manner of crystallization of a mineral is so characteristic that the forms of its crystals serve to distinguish it.

Color or Streak.—The color exhibited by a mineral in reflected light may be inherent to its substance (is ideochromatic) or it may be due to impurities included in its substance (is allochromatic). Thus, common salt is white or colorless, but many specimens are gray because contaminated with a little dark clay. When in powdered form, the mineral more nearly exhibits its true color than when in larger masses, because the quantity of impurity in a grain of powder is too small to affect its color materially. The most convenient method of viewing the powder of a mineral is by examining the mark, or streak, made by drawing it across a piece of rough porcelain or other hard, white substance. The color of a mineral's streak is, therefore, more characteristic than that of its large fragments.

Luster.—The amount and character of the light reflected from a surface is known as its luster. If a

substance is opaque and none of the light that falls upon it penetrates its surface, its luster is like that of metals, is metallic. If a portion of the incident light is diffracted and the surface exhibits a play of colors as does a pearl, or the inside of a mussel shell, its luster is pearly. Other lusters are glassy or vitreous, greasy, silky, etc.

Hardness.—The hardness of a substance may be tested by comparing it with a standard series of substances of different grades of hardness. Among mineralogists the standard scale of hardness, known as Moh's scale, consists of ten minerals arranged according to their increasing hardness as follows:

Moh's Scale of Hardness

1. Talc	6. Feldspar
2. Gypsum	7. Quartz
3. Calcite	8. Topaz
4. Fluorite	9. Corundum
5. Apatite	10. Diamond

A mineral that will not scratch any given mineral in the scale of hardness nor be scratched by it possesses an equal hardness. If it scratches one of the scale minerals and is scratched by the next hardest one, its position with respect to hardness is between the two. Thus, a mineral that scratches feldspar but is scratched by quartz has a hardness between 6 and 7.

A mineral that can be scratched by the thumb-nail has a hardness of 2 or less; if it can be scratched by a copper coin, its hardness is not greater than about 3.5; if by glass, its hardness is less than 5.5, and if by the blade of a pocketknife, its hardness is less than 6.5. Any mineral that will scratch quartz has a hardness exceeding 7.

Tenacity.—With respect to tenacity, substances may be distinguished as brittle, sectile, malleable, flexible and elastic. A brittle substance flies into powder when cut with a knife. A sectile substance may be cut, but it pulverizes under blows. A malleable substance flattens when hammered. A flexible substance will bend and remain bent when the action of the deforming force ceases. An elastic body will bend, but will recover its original position when the bending force is no longer active. Glass is brittle; copper, malleable; gypsum, sectile; asbestos, flexible; and mica, elastic.

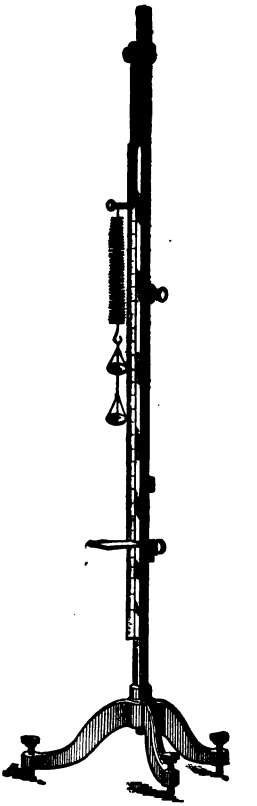


FIG. 1.—Jolly Balance.

Density.—The density of a substance compared with that of water is its specific gravity. Rock salt has a sp.gr. of 2.1; quartz of about 2.7; garnet of 3.75; magnetite of 5.2 and iron of 7.3. Since a cubic foot of water weighs about $62\frac{1}{2}$ lbs., the weight of a cubic foot of any other substance can be calculated by multiplying its sp.gr. by $62\frac{1}{2}$ lbs. In the case of minerals of similar appearance their specific gravities are often of diagnostic importance. Thus, barite ($BaSO_4$) has a sp.gr. of about 4.4, while for anhydrite ($CaSO_4$) the sp.gr. is only about 3.3. The most convenient method for determining the sp.gr. of minerals is by means of the Jolly balance (Fig. 1).

Cleavage.—Many substances that crystallize possess a marked tendency to split along certain directions in preference to others, in consequence of differences in cohesive power in different directions. This prop-

FIG. 2.—Cleavage Cracks in Calcite.

erty is known as cleavage. It is very characteristic of certain substances and may be used to distinguish them. For instance, calcite ($CaCO_3$) cleaves in such a way as to yield fragments that are rhombohedrons (figures bounded by six similar rhombs). (See Fig. 2.)

II

DESCRIPTION OF MINERALS

ELEMENTS

AMONG the elements that occur native are two important non-metals and three metals. All are of economic importance.

1. Diamond (C) is found in crystals, crystal fragments, crystalline masses and rounded pebbles.

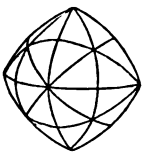


FIG. 3.—Crystal of Diamond with Curved Faces.

FIG. 4.—Photograph of Diamond Crystal.

Its crystals are octahedral in general habit, with their edges rounded, and frequently with curved faces (Fig. 3 and Fig. 4). They possess an easy cleavage parallel to octahedral planes.

The mineral is colorless, blue, yellow, gray or black, and transparent or translucent. Its streak is colorless, and its luster adamantine, i.e., like that of greasy glass. Its hardness is 10 and its sp.gr. 3.15 to 3.5. One of its most characteristic features is its high index of refraction (2.4195 for yellow light) which causes transparent stones to exhibit a marked brilliancy.

Three varieties are recognized:

Diamond, transparent, light-colored.

Carbonado, or *black diamond*, dark-colored and opaque without distinct cleavage. Sp.gr. 3.15–3.3.

Bort, dark-colored crystalline aggregates. Sp.gr. 3.5.

Before the blowpipe, diamond powder is slowly consumed. The mineral is insoluble in acids.

Diamond is easily distinguished from all other minerals by its extreme hardness.

The mineral occurs as crystals in a basic igneous rock cutting through a carbonaceous shale; as crystals and rounded pebbles in sandstones and conglomerates, and as pebbles in river sands.

The dark varieties of diamonds are used in cutting and grinding instruments. Their powder is used for polishing. Transparent varieties are cut and employed as gems.

2. Graphite is another form of carbon. It is a grayish-black substance that usually occurs in scales or in dull black, earthy masses or in small grains. When pure, it has a metallic luster, a black streak and is so soft that it leaves a mark on paper. It is easily cleavable into thin plates that are flexible. Sp.gr. is about 2.25.

It is infusible and non-combustible at the temperatures produced by the blowpipe; and it is unattacked by acids. It is distinguished from all other minerals but molybdenite (No. 8) by its color, softness and infusibility. It is distinguished from molybdenite by the absence of sulphur.

Graphite occurs as scales and plates in limestones,

shales, clays, gneisses, granites and other rocks, and in veins.

Crude graphite, plumbago, or black lead, is used in the manufacture of stove polishes and paint. Pure varieties are compressed into "centers" for lead pencils, and ground for use in lubricators.

3. Sulphur occurs in nature as a powder, as globular masses, as stalactites and in crystals (Fig. 5). When pure, it has a lemon-yellow color and streak, a glassy or resinous luster, a hardness of 1.5–2, and sp.gr. about 2. It is transparent or translucent, and brittle. It is insoluble in water or acids, but is soluble in carbon-bisulphide, chloroform and turpentine. At 113° it melts. It ignites at 270° and burns with a blue flame, producing at the same time the choking fumes of SO_2.

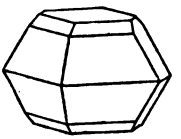


FIG. 5.—Sulphur Crystal.

Massive sulphur varies in color from yellow to brown, gray, etc., according to the impurities in it.

Sulphur is found principally in the vicinity of volcanoes and certain hot springs as powder, or as little crystals implanted on the walls of cracks in rocks, or as crystalline particles in the cavities of porous limestones associated with gypsum (No. 67).

There are only a very few minerals that are apt to be confused with sulphur. Sulphur may be distinguished from all of them by its softness, brittleness and its low melting-point.

The mineral is used principally in the manufacture of sulphuric acid, of insecticides, gunpowder, etc.

4. Copper, in its native condition, is similar to the metal in common use except that its surface is usually tarnished by a black coating, which must be removed

before the characteristic color of the metal can be seen. Its hardness is 2.5–3 and its sp.gr. 8.9.

Copper melts at a comparatively low temperature. Upon cooling, the fused mass becomes covered with a coating of black oxide. Copper dissolves in nitric acid with the evolution of brownish-red fumes of nitrous oxide and the production of a blue solution, which, upon the addition of an excess of ammonia, turns to a brilliant purple-blue. A piece of bright iron placed in the acid solution becomes covered with a coating of metallic copper. When heated in the flame of the blowpipe, copper imparts to it a green color which changes to azure-blue when the metal is touched with a drop of HCl.

Copper is easily distinguished from all other minerals but gold by its color and malleability. It is distinguished from gold by its solubility in nitric acid.

The native metal is utilized as a source of the commercial metal. Most of the metal used in the arts, however, is obtained from its compounds (see chalcopyrite, No. 17) and bornite (No. 18).

Copper occurs as grains and crystals in cavities in volcanic and sedimentary lavas, as scales between the layers of sedimentary rocks and as crystals with calcite (No. 50) in veins.

5. Silver, in its native state, is identical in its properties with the commercial metal. It is, however, usually tarnished by a black or gray stain. Silver is malleable. Its hardness is 2.5–3, and its sp.gr. 10.92.

The metal dissolves readily in dilute HNO_3, yielding a colorless solution from which a silver coating is deposited on a strip of bright copper placed within

it. Fragments fuse easily to silver-white pellets that are distinguished from lead and tin by the reaction just described and by the fact that they dissolve in HNO_3 and form a solution from which hydrochloric acid throws down a white precipitate (AgCl), which is insoluble in hot water. It is distinguished from galena (No. 9) and mica (Nos. 95–99), which it sometimes resembles in appearance, by its malleability and its silver-white color.

Silver occurs in veins, with or without other minerals, as small particles scattered through various rocks, mixed with oxidation products of a wide range of minerals in the upper portions of veins containing silver ores, and as pellets in the sands of streams (placer deposits).

6. Gold.—Native gold is the principal source of the metal used in the arts. It is similar in all respects to the commercial metal. Its hardness is 2.5–3 and sp.gr. 19.5. Its color varies with the impurities occurring with it. Silver makes its color paler and copper imparts to it a reddish tinge. Gold is so malleable that it can be hammered into sheets that are so thin as to be translucent with a blue or green color.

The mineral fuses easily in the blowpipe flame. It is insoluble in any single acid, but is dissolved in aqua-regia (2 pts. HCl and 1 pt. HNO_3).

Gold is distinguished from copper (No. 4) by its insolubility in HNO_3; from pyrite (No. 14) and chalcopyrite (No. 17) by its malleability, and from yellow mica by its insolubility and malleability.

It occurs as grains and pellets in placer deposits and associated with quartz and pyrite (Nos. 34 and

14) in veins. It is found also disseminated in tiny grains in slates and quartzites.

SULPHIDES

The sulphides are compounds derived from H_2S by the replacement of the H by metals. All sulphides when roasted yield SO_2 and, when fused on charcoal with Na_2CO_3, they form Na_2S, which is soluble in water. The solution placed on a clean piece of silver will produce a brown or black stain. Most of the sulphides are mined as ores of the metals.

7. Stibnite (Sb_2S_3) is the principal ore of antimony. It occurs in acicular and prismatic crystals (Fig. 6), in radiating groups of crystals and in fibrous masses. Many of the crystals are curved or bent and nearly all are vertically striated.

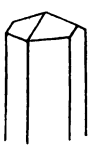


FIG. 6.—Stibnite Crystal.

Stibnite is dark gray and its streak a little darker. Exposed surfaces are often coated with a black or iridescent tarnish. Its luster is metallic in masses; but thin splinters are translucent in reddish tints. It is soft (H. = 2) and its sp.gr. is about 4.5. It fuses very easily, thin splinters being melted even in the flame of a candle. It cleaves easily along one plane.

When heated on charcoal, stibnite yields white fumes of antimony oxide (Sb_2O_3) and at the same time the choking fumes of SO_2. The former cover the charcoal near the assay with a white coating. Heated in an open glass tube, SO_2 is evolved and a white sublimite of Sb_2O_3 is deposited on the cool portions of its walls. The mineral is soluble in HNO_3 with the precipitation of a white or yellow powder (Sb_2O_5).

Stibnite may be distinguished from all minerals but the sulphides by the test for sulphur (p. 146). From the sulphides it is distinguished by its easy cleavage in one direction, its low fusibility, and the white fumes evolved by heating on charcoal. The mineral it most closely resembles is galena (No. 9).

Stibnite occurs in quartz veins and in metalliferous veins associated with lead, zinc and mercury ores.

It is used in the manufacture of safety matches, percussion caps, fireworks, and as an ore of antimony.

8. Molybdenite (MoS_2) bears a close resemblance to graphite ~~(No. 2)~~. It is black, soft and sectile. Its density is 4.7. Its color is lead black and its streak greenish-black. In very thin plates it is translucent with a greenish tinge. It occurs in plates that cleave readily into thin pieces that are flexible.

Molybdenite is infusible, but it imparts to the edges of the blowpipe flame a yellowish-green color. It yields all the reactions for sulphur and when heated in an open glass tube it deposits a pale yellow sublimate of MoO_3 on the cooler portions of the walls. The mineral is decomposed by HNO_3 with the production of a gray powder (MoO_3).

Its softness and color distinguish it from all minerals but graphite ~~(No. 2)~~ and some forms of pyrolusite ~~(No. 41)~~. From these it is easily distinguished by the reactions for sulphur (p. 163) and molybdenum (p. 160).

Molybdenite is the principal ore of molybdenum, salts of which are used in the chemical laboratory and for imparting a green color to porcelain. The metal is used in an alloy (ferro-molybdenum) for hardening steel.

The mineral occurs as grains embedded in limestone and crystalline rocks and as plates and irregular masses in quartz veins.

9. Galena (PbS) is the principal ore of lead. It

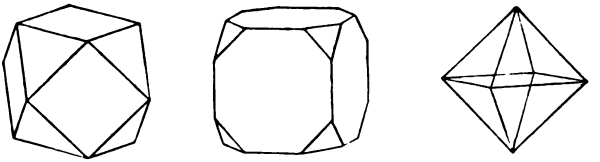


FIG. 7.—Galena Crystals.

is found in large and small isometric crystals that are usually cubic or octahedral in habit (Fig. 7 and Fig. 8), in coarse and fine granular aggregates and in great crystalline masses. It is lead gray in color and has a

FIG. 8.—Galena Crystals on Rock. (After U. S. Geol. Survey.)

grayish-black streak. Its luster is metallic, its hardness about 2.5 and its sp.gr. about 8.5. It is characterized by three cleavages perpendicular to one another, which yield cubical fragments.

Heated on charcoal, galena fuses, yielding sulphurous fumes and a globule of metallic lead, which may easily be distinguished from silver (No. 5) by its softness. Near the assay the charcoal is coated with a yellow sublimate of PbO. Galena is soluble in HNO_3 with the separation of sulphur.

Its color and luster distinguish galena from all minerals but stibnite (No. 7). From this it is distinguished by its more difficult fusibility, by its cubical cleavage and by the fact that it does not yield white antimony fumes.

Galena is found in veins associated with quartz (No. 34), calcite (No. 50), barite (No. 63), fluorite (No. 29) and sphalerite (No. 10); in irregular masses filling crevices in limestone and in other less common forms. The variety that occurs in veins often contains enough silver to make it an ore of this metal.

Galena is employed in glazing common stoneware, in the preparation of white lead and other pigments, and, as has already been stated, it is an important ore of lead and, in some cases, of silver.

10. Sphalerite (ZnS) or **blende** is the principal ore of zinc. It occurs in handsome isometric crystals that have a tetrahedral habit (Fig. 9), in grains scattered through limestones, in crusts and in stalactitic and globular masses.

Although pure zinc sulphide is white, most sphalerite is yellow or brown and translucent, or black and nearly opaque. Its streak is brown, yellow or white. The yellow translucent masses look like rosin. The luster of the mineral is resinous, its hardness 3.5–4 and sp.gr. about 4. It possesses three perfect cleavages making 120° with each other, so that almost

perfect dodecahedrons may sometimes be split from homogeneous pieces.

Sphalerite is, with difficulty, fusible. When heated on charcoal, it volatilizes slowly, coating the coal with a white sublimate which changes to yellow upon cooling. If moistened with a drop of dilute cobalt nitrate solution and heated by the reducing flame, the white sublimate changes to green. The mineral dissolves in HCl, yielding sulphureted hydrogen, and gives the other usual tests for sulphur (p. 146).

Sphalerite is found disseminated through limestone, and in streaks and veins in the same rock and in veins

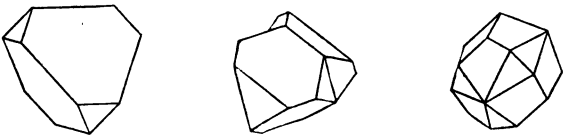


FIG. 9.—Sphalerite Crystals.

in siliceous rocks. It is often associated with galena (No. 9), chalcopyrite (No. 17), fluorite (No. 29), barite (No. 63) and silver ores.

The mineral is used in the manufacture of zinc white (ZnO) and as an ore of the metal.

11. Chalcocite (Cu_2S) and **Covellite** (CuS) are important copper ores in some places.

Chalcocite usually occurs in black masses with a dull metallic luster and in a black sooty powder, in the upper portions of veins of copper ores. It is found also in crystals. Its hardness is 2.5–3 and its sp.gr. about 5.7. Its streak, like its color, is black, but exposed surfaces are often tarnished blue or green.

12. Covellite or **indigo copper** has a dark blue color on fresh fractures. Its streak is lead gray or black and its luster is dull or metallic. Its hardness is 1.5–2 and its sp.gr. about 4.6. It usually occurs in masses, but crystals are known.

When heated in the open glass tube or on charcoal, both minerals give sulphurous fumes. When mixed with Na_2CO_3 and heated, copper globules are produced. Both minerals dissolve in HNO_3, producing a blue solution that yields the tests for copper (p. 146). When heated in thin splinters by the blowpipe flame, they impart to it a green color. They also give the copper beads (p. 141).

They are distinguished from other minerals by their color, their reactions for copper and the absence of reactions for iron (p. 138). They are distinguished from each other by their colors on fresh fractures, by their sp.gr., and the fact that when heated on charcoal covellite ignites.

13. Cinnabar (HgS) is the only compound of mercury that occurs in sufficient quantity to constitute an ore.

It occurs both crystallized and in granular masses. It is cochineal-red, inclining to brown, in color and its streak is scarlet. It is opaque, translucent or transparent, has a hardness of 2–2.5 and a sp.gr. of 8. It is also slightly sectile.

When heated gently in an open glass tube, it yields SO_2 and drops of mercury. Before the blowpipe on charcoal, it volatilizes completely, giving off SO_2.

It is easily distinguished from all other minerals by its high sp.gr., its color and the reactions for sulphur (p. 146). Earthy varieties may be confused with red

ocher (No. 38), but the reaction on charcoal sufficiently distinguishes them.

Cinnabar occurs in veins cutting volcanic rocks and neighboring sedimentary rocks.

14. Pyrite, or iron pyrites (FeS_2), **Marcasite** (**15.**), white pyrites or magnetic pyrites (FeS_2), and Pyr-

FIG. 10.—Group of Cubic Pyrite Crystals.

rhotite (Fe_nS_{n+1}) are the most important sulphides of iron. The first two are used largely in the manufacture of sulphuric acid.

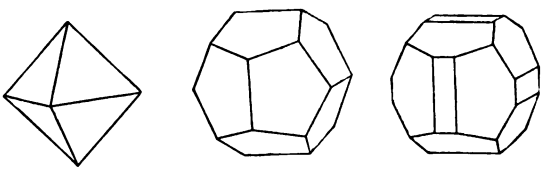


FIG. 11.—Pyrite Crystals.

Pyrite and marcasite have the same chemical composition (FeS_2), but they crystallize in different systems, the former usually in cubes (Fig. 10), octahedrons and pyritoids (Fig. 11), and the latter in flat crystals (Fig. 12), often forming radiating groups that may be disk-like or globular.

Pyrite is one of the commonest of all minerals, being found in a great variety of forms under very many different conditions. It frequently occurs in crystals and often in coarsely granular masses. It has a metallic luster, a bright yellow or brassy color, and a greenish or brownish-black streak. Its hardness is 6–6.5 and its sp.gr. about 5. It strikes fire with steel.

In the closed glass tube, it gives a sublimate of sulphur and a magnetic residue. On charcoal before the blowpipe, it ignites and burns with the pale blue flame of sulphur, producing SO_2. When treated with

FIG. 12.—Marcasite Crystal and Group of Crystals.

nitric acid, it dissolves, leaving a flocculent residue of sulphur.

In some of its forms, pyrite resembles gold in appearance; hence, its popular name, "fool's gold". It is easily distinguished from all other minerals but marcasite (No. 15) and chalcopyrite (No. 17) by its color and brittleness, and from chalcopyrite by its greater hardness and the absence of a reaction for copper. It cannot be distinguished from marcasite by any simple means, except when in crystals.

Pyrite and marcasite are mined as sources of sulphur for use in the manufacture of sulphuric acid. After driving off the sulphur by roasting, the residue (Fe_2O_3) is utilized as a red paint-pigment. Often

gold is mixed with the pyrite, when the mineral becomes a source of the precious metal.

When exposed to the air, pyrite rusts and changes to limonite No. 45; consequently, veins of pyrite at their outcrops are often marked by a rusty deposit of limonite and other oxidized compounds, known as *gossan*.

16. Pyrrhotite is the name applied to a series of compounds, the composition of which ranges between FeS and Fe_7S_8. Usually the mineral is in bronze-gray granular masses that tarnish to bronze upon exposure to the air. Only rarely does it occur in crystals. Pyrrhotite is opaque and has a metallic luster. Its color varies between bronze-yellow and copper-red and its streak is grayish-black. Its hardness is a little less than 4 and its sp.gr. about 4.5. It is magnetic.

Pyrrhotite gives the usual reactions for iron (p. 157) and sulphur (p. 146) and sometimes, in addition, those of cobalt and nickel (p. 160). It is soluble in HCl with the evolution of H_2S which may easily be detected by its odor.

It is easily distinguished from all other minerals by its color, its magnetism and its reaction for sulphur.

It is found in veins, as impregnations in various rocks and as masses enclosed in the coarse-grained, dark, igneous rock, known as *norite*. It is mined in a few instances as a source of sulphur, but at its principal occurrence, Sudbury, Ont., it is mined as a source of nickel, because there is intermixed with it at this place appreciable quantities of *pentlandite*, which is (Fe,Ni)S.

17. Chalcopyrite ($CuFeS_2$), and **Bornite** (**18.**) (Cu_3FeS_3) are usually regarded as copper salts of iron acids—the second, as a salt of the ortho-acid, H_3FeS_3, and the first, as the salt of the derived acid, $HFeS_2$($H_3FeS_3 - H_2S = HFeS_2$). Both are important ores of copper, chalcopyrite furnishing the greater part of the commercial metal.

Chalcopyrite ($CuFeS_2$) occurs both in crystals and massive. Its crystals are usually elongated tetrahedrons (Fig. 13).

The mineral has a red-brass color and a greenish-black streak. Exposed surfaces are often tarnished

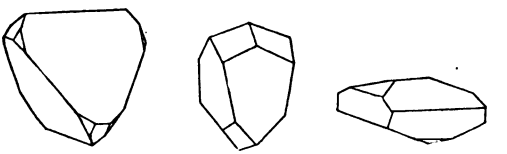


FIG. 13.—Crystals of Chalcopyrite.

with an iridescent coating. Its hardness is 3.5–4, and its sp.gr. about 4.2.

When heated on charcoal, chalcopyrite fuses to a magnetic globule. When heated in a glass tube, it reacts for sulphur (p. 146). It dissolves in HNO_3, forming a green solution in which float spongy masses of sulphur. The addition of ammonia to these solutions changes their color to deep blue and at the same time causes a precipitation of foxy-red ferric hydroxide.

From the few other brass-colored minerals chalcopyrite is distinguished by its inferior hardness, its streak and the reactions for copper (p. 146).

The mineral occurs in veins either alone or associated with other compounds of copper and iron. It

is also frequently associated with sphalerite and galena (Nos. 10 and 9).

It is an abundant ore of copper. Much of the copper obtained from it contains gold or silver or both, so that it is in some mines an important source of these metals.

18. Bornite or **horseflesh ore** (Cu_3FeS_3) is commonly found massive. It is a purplish-red metallic mineral with a grayish-black streak. Upon exposure to moist air it becomes covered with an iridescent tarnish. Its hardness is about 3 and its sp.gr. 3.

It dissolves in HNO_3 with the separation of sulphur and gives the usual blowpipe reactions for Cu, Fe and S. When its solution in HNO_3 is treated with an excess of ammonia, an intense purplish-blue color results.

Bornite is easily distinguished by its peculiar color on fresh fracture surfaces.

It is usually associated with other copper ores in veins. It is the principal ore of copper in many South American mines.

ARSENIDES AND SULPH-ARSENIDES

The arsenides and sulph-arsenides are analogous to the sulphides. In the latter, a portion of the sulphur in sulphides may be regarded as being replaced by As and, in the former, all of it. These compounds when heated before the blowpipe give off voluminous white fumes that have a characteristic odor which is usually described as resembling that of garlic. Analogous compounds, containing antimony, when heated, also yield voluminous white fumes, but they are without distinct odor.

19. Niccolite (NiAs) is the most widely distributed nickel compound, though not an important ore. It usually occurs massive as the filling of veins.

It is opaque, has a metallic luster, a pale copper-red color and a brownish-black streak. The surfaces of nearly all specimens are tarnished with a grayish coating. Its hardness is about 5 and its density 7.6.

In the open glass tube niccolite yields arsenic fumes and often traces of SO_2. When fused on charcoal with Na_2CO_3, it yields a metallic globule which gives the reactions for nickel (p. 160). The mineral dissolves in HNO_3, giving an apple-green solution which becomes sapphire-blue on the addition of an excess of ammonia.

Niccolite is easily distinguished from all other minerals by its color and its reactions for nickel.

It occurs principally in veins associated with silver and cobalt arsenides and sulphides.

20. Cobaltite (CoAsS) and (**21.**) **Smaltite** ($CoAs_2$) are the two most important ores of cobalt. They are both silver-white in color and have a grayish-black streak. Both occur in crystals like those of pyrite (No. 14), more often in those of octahedral habit (Fig. 14), and in granular masses.

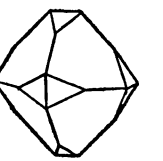


FIG. 14.—Cobaltite Crystals.

Cobaltite has a fairly good cubic cleavage, a hardness of 5.5 and a sp.gr. of about 6.2.

When heated in the open glass tube it gives a white sublimate of As_2O_3, arsenic fumes and SO_2 gas. On charcoal before the blowpipe, it yields a magnetic globule which, when fused with borax on platinum wire, gives the deep blue bead of cobalt (p. 141).

It is soluble in HNO_3, yielding a rose-colored solution and a precipitate of sulphur.

Smaltite is without distinct cleavage. Its hardness is 5 to 6 and sp.gr. 6.3–7. Its reactions in the glass tube and on charcoal are like those of cobaltite except that it gives off no SO_2. It is soluble in HNO_3 with precipitation of As_2O_3.

The two minerals are distinguished from all others by their color and their reactions for cobalt (p. 155). From one another they are distinguished by the presence or absence of sulphur.

Both minerals occur in veins. On the surface these veins are usually marked by the presence of rose-colored erythrite (No. 77), which coats both minerals wherever they are exposed to the action of moist air.

Cobalt salts are used in the manufacture of blue enamels, blue glass and blue and green pigments.

22. Arsenopyrite or **mispickel** (FeAsS) is the most important ore of arsenic. It is, however, not of great value, since most of the arsenic of commerce is obtained as a by-product (at least in North America) from the fumes of smelters that use arsenical copper ores.

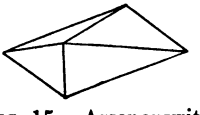


Fig. 15.—Arsenopyrite Crystals.

Arsenopyrite occurs in crystals (Fig. 15) and in compact and granular masses. It is a silver-white metallic mineral closely resembling cobaltite (No. 20) and smaltite (No. 21) in appearance, but, unlike these, it does not give the blue bead with borax, nor is it in isometric crystals.

The mineral is brittle, but it has one good cleavage. Its hardness is 5.5–6 and its sp.gr. is 6.2. Its color is silver-white to steel-gray and its streak grayish-black.

When heated in the closed glass tube, arsenopyrite gives a red sublimate of As_2S_3 and later a black mirror of metallic arsenic. On charcoal it gives the usual reactions for arsenic (p. 151) and sulphur (p. 146), and yields a magnetic residue. The mineral yields sparks when struck with steel and gives off an arsenic odor. It dissolves in HNO_3 with the separation of sulphur.

It is distinguished from cobaltite and smaltite (Nos. 20 and 21) by the absence of cobalt.

It is found in crystals scattered through crystalline rocks and embedded in the gangue of veins and as structureless masses filling veins. It is usually associated with silver and lead ores, chalcopyrite, pyrite, and sphalerite (Nos. 17, 14, 10).

SULPH-ARSENITES AND SULPH-ANTIMONITES

The ortho-sulph-arsenites are salts of the sulphur acid $As(SH)_3$ which corresponds to the oxygen acid $As(OH)_3$ or H_3AsO_3. The ortho-sulph-antimonites are salts of the corresponding antimony acids. Other sulpho compounds are salts of acids which may be regarded as derived from these.

23. Proustite (Ag_3AsS_3) and (**24.**) **Pyrargyrite** (Ag_3SbS_3) are two important ores of silver. The former is known also as light-ruby silver and the latter as dark-ruby silver. Both occur as complicated crystals (Fig. 16) in veins and as grains mixed with other minerals, forming compact masses. Both minerals are gray in reflected light and ruby-red in transmitted light. Proustite is more nearly transparent in thin splinters than is pyrargyrite and has a brighter color. The streak of proustite is bright red and that of pyr-

argyrite purplish-red. Their hardness is 2.5. The sp.gr. of proustite is 5.6 and of pyrargyrite 5.85.

When heated in the closed tube proustite fuses easily and gives a slight reddish-yellow sublimate of As_2S_3. Pyrargyrite, under the same conditions, yields a reddish-brown sublimate of antimony oxysulphide. When fused with Na_2CO_3 on charcoal, both give a globule of silver, but proustite yields the white garlicky fumes of As, while pyrargyrite yields odorless fumes. Both give the ordinary reactions for sulphur (p. 146). Both minerals dissolve in HNO_3 with the separation of sulphur and, in the case of pyrargyrite, with the precipitation also of white Sb_2O_3.

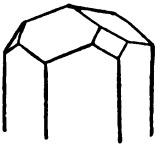


FIG. 16.—Pyrargyrite Crystals.

The two minerals are distinguished from all others by their color in thin splinters and their reactions for silver and sulphur. They are distinguished from one another by their streaks and the reactions for As or Sb.

Both minerals are mined with others as silver ores, especially in South America and in some portions of the western United States.

25. Tetrahedrite is the name usually given to a mixture of $(Ag \cdot Cu)_8Sb_2S_7$ and $(Ag \cdot Cu)_8As_2S_7$. The mineral is fairly common in veins carrying silver and copper ores. In some places it is mined as a source of silver. It is known also as *gray copper ore*.

Frequently, tetrahedrite occurs in tetrahedral crystals (Fig. 17), but more frequently it is found in masses. Its color is steel-gray and its streak steel-gray or gray-black, often with a tinge of brown. Its luster is metallic. Its hardness is 3–4 and sp.gr. about 4.5.

When heated on charcoal or in the open glass tube, both the arsenic and the antimony varieties yield SO_2 and dense white fumes which, in the case of the antimony varieties (tetrahedrite), have no odor, and, in the case of the arsenic variety (tennantite), have the garlic odor of arsenic oxide. Heated in the closed tube, the mineral fuses and, if it contains antimony, gives a red sublimate of antimony oxysulphide, or if an arsenic variety, a white sublimate of As_2S_3 results. Both varieties dissolve in nitric

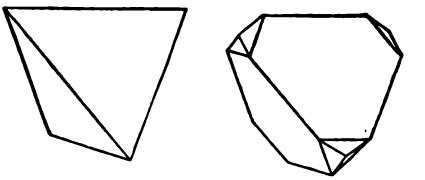


FIG. 17.—Tetrahedrite Crystals.

acid, yielding sulphur and a solution which gives the tests for copper (p. 155). In the antimonial varieties there is also a separation of Sb_2O_3.

Tetrahedrite is easily recognized by its crystals, its color and hardness. Massive forms are distinguished by their inferior hardness and their blowpipe reactions.

CHLORIDES AND FLUORIDES

Chlorides and fluorides are derived from HCl and HF by the replacement of hydrogen by metals.

26. Cerargyrite (AgCl) or **horn silver** is an important silver ore in some camps. Although occasionally occurring in cubical crystals, it is more frequently found as waxy masses without well-defined structure.

It is a colorless, white or gray translucent mass with a waxy luster and a white streak. Upon exposure to light, it tarnishes to brown, violet or black. Its hardness is 1 to 1.5 and sp.gr. 5.5. It can be cut into shavings with a sharp knife (is sectile).

In the closed tube, it fuses without decomposition. When heated on charcoal, it yields a globule of silver and when heated with copper oxide in the blowpipe flame it gives the chlorine reaction (p. 146). It is insoluble in HNO_3, but is soluble in ammonia. From this solution HNO_3 throws down a white precipitate.

Cerargyrite is distinguished by its sectility, its waxy luster and the reactions for Ag and Cl.

It is found in the upper portion of veins containing silver ores.

27. Halite (NaCl) or **common salt** is the best known of the chlorides. It is a transparent mineral

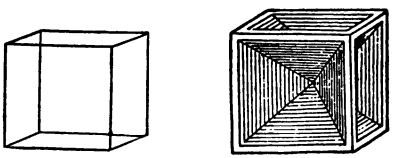


FIG. 18.—Halite Crystals.

occurring in crystals and in granular or compact masses.

Its crystals are usually cubes, often with depressed faces (Fig. 18). When pure, halite is colorless, but the impurities often present color it red, gray, yellow or blue. Its hardness is 2.5 and its sp.gr. 2.3. Its luster is vitreous. It is readily soluble in water and possesses a salty taste.

In the closed glass tube, it fuses and many specimens decrepitate. When heated before the blowpipe, it colors the flame yellow. If a small quantity is fused on a platinum wire and sprinkled with a little powdered copper oxide, and then heated before the blowpipe, the flame will become bright blue. The mineral easily dissolves in water and its solution yields an abundant white precipitate with silver nitrate.

Halite is easily distinguished from other soluble minerals by its salty taste; the yellow color it imparts to the blowpipe flame and the reaction for chlorine.

It is found in beds interstratified with other substances deposited from water, and in solution in the ocean, salt lakes and the brines saturating certain limestones and sandstones.

This mineral is the chief source of sodium compounds. It is employed in glazing pottery, in enameling, in metallurgical processes and many more familiar operations.

28. Sylvite (KCl) is one of the chief sources of potassium salts. It is like halite in its occurrence and in most of its properties. Its hardness, however, is 2 and its sp.gr. 1.99.

When heated before the blowpipe, it imparts a violet tinge to the flame, which can be detected when masked by the yellow flame of sodium by viewing it through blue glass. Otherwise, sylvite and halite react similarly.

It is distinguished from halite by the violet color it imparts to the flame.

29. Fluorite (CaF), fluorspar, is the principal source of fluorine. As usually found, it is a transparent mineral that is characterized by its fine color

and handsome crystals. It occurs also granular, fibrous and massive.

Fluorite is isometric. Its crystals are usually cubes, octahedrons or combinations of both. Frequently, the cubes are intergrown (Fig. 19). The

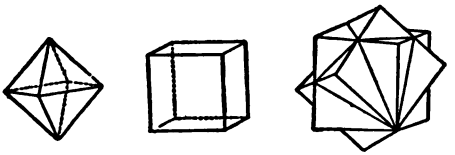


FIG. 19.—Fluorite Crystals.

mineral is transparent, and white, yellow, green, purple or red. Its streak is white, its luster vitreous, and its cleavage octahedral. It is brittle. Its hardness is 4 and sp.gr. about 3.2.

In the closed tube, fluorite decrepitates and phosphoresces. When heated on charcoal it fuses, colors the flame yellowish-red and yields an enamel-like residue that reacts alkaline. Its powder, treated with H_2SO_4, yields hydrofluoric acid (HF) which etches glass.

Fluorite is easily distinguished from all other minerals by its crystallization, hardness, cleavage and the reaction for fluorine (p. 148).

It occurs in veins, often mixed with metallic ores, and as crystals on the walls of cavities in rocks.

It is used as a flux in smelting iron and other ores, in the manufacture of opalescent glass and of the enamel used on cooking utensils; it is also employed in making HF, which, in turn, is used in etching glass. The brighter colored varieties are employed in cheap jewelry and as an ornamental stone.

NITRATES

The two most important nitrates are (**30.**) **Niter** (KNO_3), and (**31.**) **Soda-niter** ($NaNO_3$). The first is known also as *saltpeter* and the latter as *Chile saltpeter.*

Both are colorless, transparent minerals that are soluble in water. Both occur massive, as incrustations and as the cement of soil grains. Niter is also found in tufts of acicular crystals. Both minerals have a hardness of about 2, and a sp.gr. of 2.1 to 2.25.

Both deflagrate when heated on charcoal and soda-niter deliquesces and finally liquefies. They both yield the tests for HNO_3 (p. 161) and both have a cooling taste. Niter colors the blowpipe flame violet and soda-niter imparts a yellow tinge.

The two minerals occur in the soil of rainless or very dry regions and niter in the soil covering the floors of caves.

The niters are used in the production of HNO_3 and in the manufacture of fertilizers and gunpowder.

BORATES

The two borates of most importance are (**32.**) **Borax** ($Na_2B_4O_7 \cdot 10H_2O$), and (**33.**) **Colemanite** ($Ca_2B_6O_{11} \cdot 5H_2O$). Both are commercial products.

Borax occurs as crystals (Fig. 20), as a crystalline cement of sand grains around certain salt lakes, and as incrustations on the surfaces of marshes and the sands of deserts.

It is a white, gray or bluish transparent or translucent mineral with a white streak. It has a vitreous,

resinous or earthy luster and is brittle. Its hardness is 2–2.5 and its sp.gr. 1.7. On exposure to the air, borax loses water and tends to become white and opaque. The mineral is soluble in water and has a sweetish, alkaline taste.

Before the blowpipe, borax puffs and fuses to a transparent globule, at the same time coloring the flame yellow. When moistened with H_2SO_4 and heated, the flame becomes tinged with green. When dissolved in HCl, its solution will turn turmeric paper reddish-brown after drying at 100°. When the stain is moistened with ammonia, it changes to black.

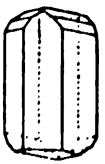


Fig. 20.—Borax Crystal.

Purified borax is used as an antiseptic and preservative in medicine, in cosmetics and in the manufacture of enamels, glazes and glass. Most of the borax used in the arts is made from colemanite.

Colemanite occurs in handsome crystals (Fig. 21), and in granular and compact masses.

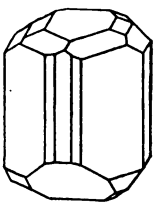


Fig. 21.—Colemanite Crystal.

It is colorless, milky-white, yellowish, white or gray, and is transparent or translucent. It has a vitreous luster and a white streak. Its hardness is 4–4.5 and its sp.gr. is 2.4.

Heated before the blowpipe, it decrepitates, exfoliates and partially fuses, at the same time coloring the flame yellowish-green. It is soluble in hot HCl, but upon cooling the solution a voluminous mass of boric acid separates as a gelatinous precipitate.

Colemanite is easily distinguished from other white, translucent minerals by the flame test and the gelatinous precipitate from its cooled, hydrochloric acid solution. It is best distinguished from borax by its insolubility in water and its greater hardness.

The mineral occurs in layers interstratified with clay and gypsum and in veins cutting lake deposits.

Colemanite is the principal source of the boric acid and borax used in the arts.

OXIDES

The mineral oxides may be regarded as compounds in which all the hydrogen of water (H_2O) has been replaced by metals. Hydroxides may be regarded as those in which only part of the hydrogen is thus replaced.

34. Quartz (SiO_2) is one of the commonest of all minerals. It occurs as crystals (Fig. 22) and crystal-

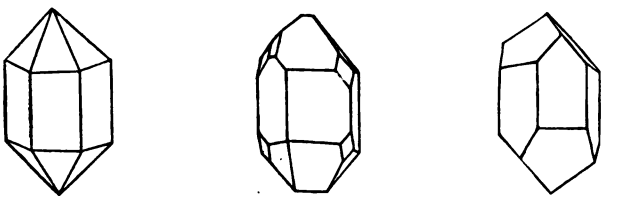


FIG. 22.—Quartz Crystals.

line masses, in veins, as grains in crystalline rocks and as small fragments in sand and sandstones. It is one of the commonest decomposition products of weathered rocks.

Quartz is transparent and colorless, or white, when pure, but it may have almost any color when impure.

Its crystals are hexagonal prisms terminated by trigonal or hexagonal pyramids. They may be nearly equidimensional or they may be elongated into columnar or acicular forms. Its hardness is 7 and its sp.gr. 2.65. It is insoluble in all ordinary acids, but is vigorously attacked by HF.

It is infusible before the blowpipe and does not react with any of the ordinary reagents.

It is distinguished from most minerals by its hardness and from the few other equally hard, transparent ones by its infusibility and general stability toward reagents.

Its most common crystallized varieties are:

Rock crystal, rhinestone, etc., a transparent, colorless phase.

Amethyst, violet colored.

Citrine, or *false topaz,* a yellow variety.

Smoky quartz, or *cairngorm stone,* a smoky-brown transparent or translucent variety.

Its common crystalline varieties are:

Milky quartz, a white translucent or nearly opaque variety.

Chalcedony, a dense translucent variety, with a waxy luster.

Carnelian, a clear red or brown chalcedony.

Chrysoprase, an apple-green chalcedony.

Plasma, a bright green, translucent chalcedony.

Heliotrope, or *bloodstone,* a plasma dotted with red spots.

Agate, a variegated or banded chalcedony or a mixture of chalcedony and quartz.

Onyx, an evenly banded agate, showing a marked contrast in colors.

Sardonyx, an onyx in which some of the bands are carnelian.

Flint and *jasper* are very fine-grained, crystalline aggregates of gray or red quartz.

Crystallized varieties are used as gems and also in the construction of optical instruments and in the manufacture of cheap jewelry. Milky quartz is ground and used as an abrasive, in the manufacture of sandpaper and in the making of earthenware. Quartz sand is utilized in making glass, and in the form of sandstone it is used as a building stone. Crushed quartz is also employed in some smelting operations.

35. Cuprite (Cu_2O) is an important oxide of copper, but not a common ore of the metal. It occurs in isometric crystals which have octahedral (Fig. 23) or cubical habits and in capillary, earthy and granular aggregates. It is also found massive.

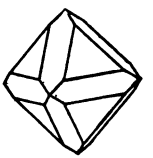


FIG. 23.—Cuprite Crystal.

It is opaque, translucent or even transparent in different specimens. Its luster may be vitreous or earthy and its color is red, brown and, in rare cases, black by reflected light and crimson by transmitted light. Its streak is brownish-red and it has a brilliant luster. When rubbed with the finger it becomes yellow and finally green.

Before the blowpipe, cuprite fuses and colors the flame green. If moistened by HCl and heated, the color of the flame becomes bright blue. Heated on charcoal, the mineral fuses and upon long-continued heating yields a globule of copper. It dissolves in strong HCl, forming a solution which, when cooled and diluted with water, gives a white precipitate of

Cu_2Cl_2. It also gives the common reactions for copper (p. 155).

Cuprite may easily be distinguished from almost all other red minerals by its reactions for copper. Moreover, it is harder than cinnabar and proustite and softer than hematite (Nos. 13, 23, 38).

It is found alone or associated with other copper minerals in veins, and disseminated as tiny grains in certain sedimentary rocks.

It is mined with other minerals as an ore of copper.

36. Zincite (ZnO) is a comparatively rare mineral, but it occurs in such large quantity at Franklin Furnace, N. J., that it is utilized as an ore of zinc.

Zincite is only occasionally found in crystals. It usually occurs massive or as grains in limestone, associated with other zinc minerals.

The mineral is colorless or red (in consequence of the presence of manganese) and it has a colorless or an orange streak. It cleaves easily in one direction. Its hardness is 4–4.5 and its sp.gr. about 5.5.

When heated in the closed tube, the red variety of zincite blackens, but it resumes its original color upon cooling. With the borax bead, it gives the manganese reaction (p. 141). Heated on charcoal, it produces a white coating, which turns green when moistened with cobalt solution and heated with the oxidizing flame (p. 147). It is soluble in acids.

Red zincite is not easily confused with other minerals. It is identified by its color and the reaction for zinc.

Corundum (Al_2O_3) is the hardest known mineral with the exception of diamond. In consequence of its great hardness, it is used as an abrading agent

under the name of emery. It also furnishes the most valuable of the gems.

The mineral occurs in crystals and in granular masses. Its crystals are pyramidal or barrel-shaped (Fig. 24), and are usually rough with rounded edges. The mineral is transparent or translucent, has a glassy luster, a hardness of 9 and a sp.gr. of 4. Its color varies from white, through gray to various shades of

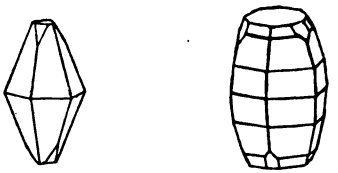


FIG. 24.—Corundum Crystals.

red, yellow or blue. Some specimens are colorless. Its streak is uncolored.

The three most important varieties are:

Corundum, dull-colored varieties used as polishing material.

Emery, impure black, granular variety, used as an abrasive.

Sapphire, the transparent, colored varieties which are used as gems.

Jewelers divide sapphires into sapphires, possessing a blue color; rubies, having a red shade; oriental emeralds, oriental topazes and oriental amethysts, with green, yellow, and purple tints.

Powdered corundum, moistened with a few drops of cobalt nitrate and heated for a long time, assumes a blue color. The mineral gives no other characteristic reactions. It is infusible and insoluble.

It is easily characterized by its hardness.

Corundum is found in veins and scattered through dike rocks and granular limestones.

38. Hematite (Fe_2O_3) is the principal ore of iron. It occurs in large, brilliant black crystals (Fig. 25) with a rhombohedral habit, in yellow, brown and red earthy masses, in dense black, structureless masses, in granular and micaceous aggregates and in stalactitic forms.

When pure and massive, or in crystals, hematite is black, glistening and opaque, except in very thin

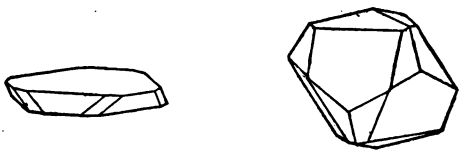


FIG. 25.—Hematite Crystals.

splinters, which are red and translucent. Earthy varieties are red. The streak of all varieties is brownish-red. The hardness of crystallized hematite is 5.5–6.5 and its density 5.2.

The mineral is infusible before the blowpipe. In the reducing flame on charcoal it becomes magnetic. It is soluble in HCl.

The dark varieties are easily distinguished by their streak and the fact that they become magnetic after heating. Red, earthy varieties may resemble cinnabar or cuprite (Nos. 13 and 35), but they are easily distinguished from these by the absence of the tests for S and Cu.

Several varieties have received special names:

Specular ore is an aggregate of glistening grains.
Ocher is a red, earthy kind.
Clay ironstone is a hard brown or red impure variety with a dull luster.
Oölitic ore is a red mass of compacted spherical or nearly spherical grains made up of concentric layers.
Fossil ore is a mass of fragments of shells composed of red hematite.

Hematite occurs in beds and irregular deposits associated with sedimentary rocks and as crystals on the walls of clefts in volcanic rocks, and in veins.

The mineral is mined as an ore and as a pigment under the name of red ocher. A fibrous variety is cut into balls and cubes for use as jewelry and the powder of some of the massive forms is used as a polishing powder.

39. Rutile (TiO_2) occurs in small, black crystals

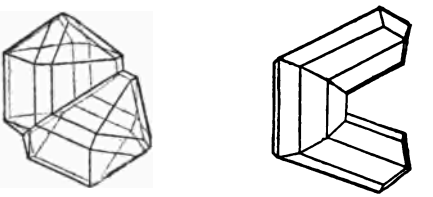


FIG. 26.—Rutile Crystals.

(Fig. 26), and in dark, purplish-brown or black masses. Its crystals are prismatic or acicular, and all are vertically striated. They possess one perfect cleavage. The mineral is reddish, yellowish-brown or black by reflected light and sometimes deep red by transmitted light. Some varieties are opaque and others translucent or transparent. Its streak is pale brown,

its hardness 6–6.5 and sp.gr. about 4.2. Two other minerals, *brookite* and *octahedrite*, have the same composition as rutile, but they crystallize differently and have different physical properties. In some of their phases they resemble rutile in general appearance.

Rutile is infusible and insoluble. With beads it gives the reactions for titanium (p. 141). When fused with Na_2CO_3 on charcoal and the resulting mass is dissolved in HCl, the solution thus obtained becomes violet when heated with scraps of tin.

Its density, infusibility and the reaction for Ti characterize the mineral. Some of the reddish-brown, massive varieties resemble garnet; but their differences in cleavage serve to distinguish them.

Rutile is used to impart a yellow color to porcelain and to give an ivory tint to artificial teeth. It is also used in the manufacture of ferro-titanium, which is employed in making certain grades of steel.

40. Cassiterite (SnO_2) or **tinstone** is the only ore of tin. It is found as rolled gravel of a dark brown color and in glistening black crystals occurring in veins with topaz (No. 91) and other minerals. It occurs also as crystals and grains in granites near veins containing the mineral. The crystals are very much like those of rutile (see Fig. 26), but some are more prismatic in habit (Fig. 27).

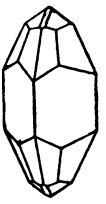


FIG. 27.—Cassiterite Crystal.

Its color is dark-brown or black, its streak white, gray or black, and its luster very glistening. The purest specimens are transparent; but ordinary varieties are opaque. Its hardness is 6.5 and sp.gr. about 7. It is only slightly affected by acids. With

some difficulty, it may be reduced to metallic tin when mixed with Na_2CO_3 and heated intensely on charcoal.

It is most easily distinguished from other minerals by its high sp.gr. and its inertness when treated with reagents.

The three varieties commonly recognized are:

Tinstone, the crystallized or massive variety.

Wood tin, botryoidal or globular masses with radial structure, and

Stream tin, pellets in gravel.

41. Pyrolusite (MnO_2) is an important source of manganese compounds. It occurs granular or in columnar masses of radiating fibers. In all cases it is probably an alteration product of other manganese compounds.

It is a soft, black, opaque mineral with a hardness of 2 or 2.5 and a sp.gr. of 4.8. Its luster is metallic and its streak black.

When heated in the closed tube, it yields a small quantity of water. With the beads it gives the usual reactions for manganese and when fused with Na_2CO_3 it gives an opaque, green enamel. Heated alone, it decomposes and evolves oxygen ($3MnO_2 = Mn_3O_4 + O_2$). It dissolves in HCl with the evolution of chlorine ($MnO_2 + 4HCl = MnCl_2 + 2H_2O + Cl_2$).

Pyrolusite is easily distinguished from other soft, black minerals by its reactions for manganese (p. 159) and from other manganese compounds by its inferior hardness.

It occurs in veins associated with other metallic compounds and intermingled with iron ores in beds and irregular deposits.

Pyrolusite is employed to neutralize the green color given to glass by iron compounds and to impart brown, black and violet colors to pottery. Some of its compounds are used as mordants in dyeing. It is also the principal compound by the aid of which oxygen and chlorine are produced. Its important use is in the manufacture of spiegeleisen, which is added to steel employed in casting car wheels.

HYDROXIDES

42. Opal (SiO_2+aq) is an amorphous compound which may be a mixture of silica and silicon hydroxide. Its content of water is variable. It is probably a colloid. It occurs in massive form, in globular and stalactitic masses and in an earthy condition. Certain varieties are used as gem stones.

When pure, opal is colorless and transparent. Usually it contains traces of impurities and may be gray, red, green or blue and translucent or opaque. The play of colors in gem opal is due to the interference of light rays reflected from the sides of thin layers of opal material of different densities. The hardness of opal is 5.5–6.5, and its sp.gr. 2.1.

All varieties are infusible before the blowpipe and all become opaque when heated. When boiled with KOH solution, some varieties dissolve easily and others very slowly.

Opal is distinguished from other amorphous substances by its hardness, infusibility and insolubility in acids. It is distinguished from chalcedony by the large quantity of water it yields upon heating.

The principal varieties are:

Hyalite, colorless, transparent.

Precious opal, transparent and exhibiting a play of colors.

Fire opal, a precious opal, in which the colors are brilliant yellow and red.

Siliceous sinter, pulverulent accumulations of white, translucent or opaque masses deposited from the waters of hot springs.

Tripoli and *infusorial earth*, pulverulent accumulations in which opal is an important constituent.

Opal occurs in deposits around hot springs, in veins cutting volcanic rocks, and as nodules embedded in limestones and slates.

Besides its use as a gem, opal in the forms of tripoli and infusorial earth is employed in the manufacture of soluble glass, polishing powders, cements, dynamite, and is used as a wood filler, an abrasive, in making paint, and in manufacturing filter stone.

43. Brucite ($Mg(OH)_2$) is a soft, white mineral, occurring in tabular crystals and in platy masses. It possesses a very perfect cleavage, splitting easily into foliæ that are flexible. It is colorless or white, inclining to bluish or greenish. It is transparent or translucent, has a hardness of 2.5 and a sp.gr. of 2.4. Its luster is pearly on cleavage surfaces.

Brucite is infusible before the blowpipe. In the closed glass tube, it gives off water and the powder left reacts alkaline. When moistened with solution of cobalt nitrate and heated, it becomes pink. The pure mineral is completely soluble in acids.

Brucite may be confused with gypsum (No. 67),

talc (No. 105), diaspore and some micas. It is distinguished from diaspore and mica by its inferior hardness; from talc, by its solubility in acids and from gypsum ($CaSO_4+2H_2O$) by the test for sulphur (p. 146).

44. Bauxite ($Al_2O(OH)_4$) is the principal ore of aluminium. It occurs in concretionary, or oölitic, grains (Fig. 28), in earthy, clay-like forms and massive,

FIG. 28.—Oölitic Form of Bauxite.

usually in pockets or lenses in clay, resulting from the alteration of limestone.

The mineral is white when pure; but, as usually found, is gray, yellow, red or brown. It is translucent to opaque and has a colorless or very light streak and dull luster. Its hardness varies between 1 and 3 and its sp.gr. is 2.55.

Before the blowpipe bauxite is infusible. It yields water at a high temperature. When moistened with a few drops of cobalt nitrate solution and heated, its powder turns blue. It is with difficulty soluble in hydrochloric acid.

Concretionary forms of bauxite are easily distinguished by their appearance and the blue color they give with cobalt nitrate. Earthy forms may also be recognized by the blue coloration when pure. Impure varieties can be detected only by analysis.

Bauxite is the source of aluminium in the manufacture of the metal, of aluminium salts, of alundum (artificial corundum) and of bauxite brick for furnaces.

45. Limonite ($Fe_4O_3(OH)_6$) or **brown hematite** is

FIG. 29.—Botryoidal Group of Limonite Fibers.

one of the important ores of iron. It occurs in stalactitic, globular (Fig. 29), concretionary and earthy forms. Another mineral, *goethite*, resembles limonite very strongly. Moreover, it contains the same elements as does limonite, but they are combined differently. Goethite is $FeO \cdot OH$.

Limonite is a brown, dull or earthy mineral with a submetallic luster and a yellowish-brown streak. Its surface is often black and varnish-like. Its hardness is 5.5 and its sp.gr. about 3.8.

When heated on charcoal, it yields a magnetic residue. In the closed glass tube, it gives off water and is changed to red Fe_2O_3. It reacts with the beads for iron (p. 141) and easily dissolves in HCl.

It is distinguished from hematite (No. 38) by its streak, inferior hardness, and its reaction for water in the closed tube, and from goethite ($FeO \cdot OH$), by its lack of crystallization.

Three distinct varieties are:

Yellow ocher, a brownish-yellow, earthy type.

Brown clay ironstone, a compact variety often in concretionary nodules, and

Bog ore, an impure, porous variety, containing stems and leaves, found in the bottoms of ponds and marshes.

Limonite is found in beds, as nodules in various rocks and as crusts, etc., resulting from the alteration of iron-bearing minerals.

ALUMINATES, FERRITES AND CHROMITES

The minerals belonging to this group are usually regarded as oxides, but for good reasons they may

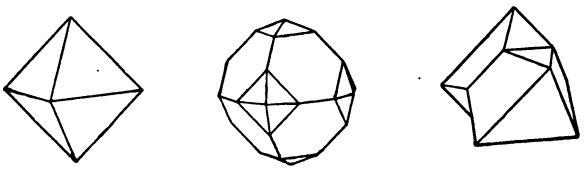


FIG. 30.—Spinel Crystals.

also be considered salts of metallic acids. Thus, magnetite (Fe_3O_4) may be looked upon as the iron salt of the acid $FeO \cdot OH$, thus $(FeO \cdot O)_2Fe$; chromite as $(CrO \cdot O)_2Fe$; spinel as a magnesium salt of $AlO \cdot OH$,

thus $(AlO\cdot O)_2Mg$; and franklinite as $((Fe,Mn)O\cdot O)_2(Fe,Zn,Mn)$.

The members of the group, which is known as the spinel group, commonly crystallize in octahedrons, or forms with octahedral habits (Fig. 30).

46. Spinel ($MgAl_2O_4$) is found in crystals, and in rolled pebbles.

It is colorless when pure, but is usually pink, blue, brown, yellow or black. Its hardness is 8 and its sp.gr. 3.5–3.6. It is infusible, but frequently changes color upon being heated. When moistened with $Co(NO_3)_2$ solution and heated, it becomes blue. It is insoluble in HNO_3 or HCl, but is slightly soluble in H_2SO_4.

The special named varieties are:

Balas ruby, or *ruby spinel*, a clear, red, transparent variety.

Ceylonite, a dark green, brown or black, opaque variety.

Picotite, a chrome spinel. It is yellowish or greenish-brown and transparent.

Spinel is easily recognized by its hardness, color, and the shape of its crystals.

It is found embedded in limestones, serpentine, gneiss and occasionally in other rocks. It is sometimes changed to talc, muscovite or serpentine (Nos. 105, 96, 104).

Transparent spinels are used as gems.

47. Magnetite (Fe_3O_4) occurs in crystals (Fig. 31) and massive. It is black, has a black streak, a hardness of 5.5–6 and a sp.gr. of 4.9–5.2. It is strongly attracted by a magnet and in many instances it exhibits polar magnetism.

The mineral is infusible before the blowpipe. Its powder dissolves slowly in HCl and the solution gives reactions for ferrous and ferric iron.

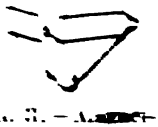


Fig. 3.—Magnetite crystals.

It is easily recognized by its color, crystallization, and magnetism.

Magnetite occurs embedded in various rocks and as the principal constituent of some veins.

It is an important iron ore.

48. Chromite $FeCr_2O_4$ closely resembles magnetite but its streak is brown and it is usually non-magnetic. Its hardness is 5.5 and its sp.gr. 4.5–4.8.

The mineral alone is infusible on charcoal, but when mixed with Na_2CO_3 and heated it yields a magnetic residue. If its powder is fused with niter No. 31 and the fusion treated with water, a yellow solution of K_2CrO_4 results. It gives the chromium reaction with the beads p. 141.

Chromite is easily distinguished from magnetite No. 47 and franklinite No. 49 by its reaction for chromium.

It occurs as crystals and grains embedded in the rock known as serpentine, and as the filling of little veins cutting it.

The mineral is the sole source of the metal chromium and of the chrome-iron alloy employed in making chrome-steel.

49. Franklinite $(Fe,Zn,Mn)_3O_4$ resembles magnetite in general appearance. It is black and lustrous and has a dark-brown streak. It is only slightly magnetic. Its hardness is 6 and sp.gr. 5.2.

It is infusible on charcoal, but yields a magnetic residue. When mixed with Na_2CO_3 and heated on

platinum in the oxidizing flame, it gives a bluish-green, opaque bead which is characteristic for manganese. If the mixture is heated on charcoal, a white coating of zinc oxide deposits around the assay and this turns to green when moistened with $Co(NO_3)_2$ and again heated.

Franklinite is distinguished from magnetite (No. 47) and chromite (No. 48) by its reactions for Mn and Zn.

The mineral is usually in crystals or grains associated with red zincite (ZnO), (No. 36) and green or pink willemite ($ZnSiO_4$), (No. 86).

It is utilized as a source of zinc, zinc oxide and is used in making the manganese alloy, spiegeleisen.

CARBONATES

The carbonates constitute an extremely important group of minerals. They are all salts of the acid H_2CO_3. Most of them are normal salts, but two important carbonates are basic salts. Some are anhydrous and others contain water of crystallization. All carbonates effervesce when their powder is treated with hot HCl, due to the evolution of the gas CO_2, and the basic ones, when heated in a glass tube, give off water.

Normal Carbonates

The normal anhydrous carbonates are divided into two groups, of which the first comprises minerals which crystallize in rhombohedrons, scalenohedrons and prisms belonging to the hexagonal system, and the second in prisms, pyramids and other forms that are orthorhombic. (Compare Figs. 32 and 36.)

50. Calcite ($CaCO_3$) is one of the commonest minerals and one of the most handsomely crystallized. Its crystals are rhombohedrons of various kinds, scalenohedrons and prisms combined with rhombo-

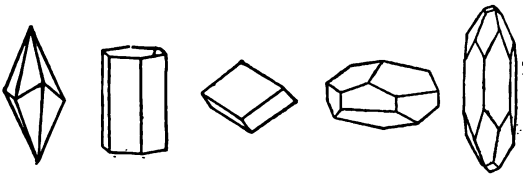


FIG. 32.—Calcite Crystals.

hedrons (Figs. 32 and 33). The mineral occurs also as stalactites (Fig. 34), in pulverulent masses, in radial and fibrous groups and in granular aggregates. The

FIG. 33.—Crystals of Calcite Attached at One End.

latter are found in very large rock masses, known as limestone and marble.

Calcite is colorless when pure and transparent. More frequently, however, it is white or some light-colored shade and translucent. Its streak is white and its luster vitreous. Its hardness is 3 and sp.gr. 2.71. Its cleavage is so perfect that the mineral

easily breaks into little rhombohedrons. It is strongly double-refracting.

Its varieties are as follows:

Iceland spar is colorless and transparent. It usually exhibits clearly its strong double refraction.

Satin spar is finely fibrous.

Limestone is a granular aggregate.

Marble is a limestone which exhibits, when broken, the glistening cleavage surfaces of fractured crystals.

FIG. 34.—Stalactite of Calcite.

Stalactites are cylinders or cones composed of radial fibers.

Mexican onyx is a banded crystalline mass of calcite which is a portion of a large stalactite.

Travertine is a deposit of white or yellow porous calcite, produced by deposits from water, often around organic material, like the blades or roots of grass.

Chalk is a fine-grained, pulverulent calcite occurring in beds.

Before the blowpipe calcite is infusible; but many specimens decrepitate. It colors the flame reddish-

yellow, and, after heating, the residue reacts alkaline. The mineral dissolves in *cold* HCl with the evolution of CO_2.

Calcite is easily distinguished from all other minerals by its easy cleavage and its solubility with effervescence in cold HCl. Its massive varieties are distinguished best from massive dolomite (No. 51), by the cold HCl reaction and from massive aragonite (No. 56) by heating its powder with a little $Co(NO_3)_2$ solution. Aragonite becomes lilac-colored, while calcite remains unchanged.

Calcite is widely distributed in beds, in veins and in loose deposits at the bottoms of springs, lakes and rivers.

It is employed in the construction of optical instruments; in the manufacture of lime and cement, and as a flux in smelting operations. It is one of the ingredients in glass-making. Calcite rocks are widely used as building and ornamental stones.

51. Dolomite ($(Ca,Mg)CO_3$) resembles calcite in most of its properties. Its crystals, however, nearly always show curved faces (Fig. 35), and often exhibit a pearly luster. Its hardness is 3.5 to 4 and its sp.gr. 2.8.

Dolomite behaves like calcite before the blowpipe, but it effervesces with cold HCl only when in the finest powder. In hot acid it dissolves easily.

Dolomite is easily distinguished from calcite by its greater hardness and its insolubility in cold acid.

The mineral occurs in the same forms as calcite. Rock masses composed of dolomite are known either as dolomite or as magnesian limestone.

52. Magnesite ($MgCO_3$) is also very much like calcite, but crystals are comparatively rare. More-

over, the mineral is usually opaque or translucent. Its hardness is about 4 and its sp.gr. 3.1.

Magnesite behaves like calcite before the blowpipe. It effervesces in hot HCl and readily yields the magnesium reaction with $Co(NO_3)_2$ (p. 147).

It is easily distinguished from calcite by its sp.gr. and by the fact that it does not effervesce readily with cold HCl. It differs from calcite (No. 50) and

FIG. 35.—Dolomite Crystals on Limestone.

dolomite (No. 51) in that it does not color the blowpipe flame with the yellow-red tint of calcium.

Magnesite usually occurs in veins and masses associated with serpentine (No. 104).

It is employed largely in the manufacture of bricks that are used for lining converters in steel works, etc. It is used also in the manufacture of paper from wood pulp; in making artificial marble, etc.; in the preparation of epsom salts, magnesia and other medicinal products; and in the manufacture of the carbon dioxide used in making soda water.

53. Siderite ($FeCO_3$) was formerly an important iron ore. It is found crystallized and massive, in botryoidal and globular forms, in nodules and in earthy masses. Its crystals are usually rhombohedrons.

Siderite is occasionally white; but more frequently is yellow or brown and when it contains manganese is pink. It is translucent or opaque. Its hardness is 3.5 and sp.gr. 3.8.

When heated in the closed tube, it decrepitates, blackens and becomes magnetic. When heated on charcoal, it leaves a magnetic residue. Its powder dissolves very slowly in cold acids, but effervesces briskly in hot ones.

It is distinguished from the other carbonates by its reactions for iron, its color and its sp.gr. It is most easily confused with rhodochrosite (No. 55), but the two minerals are differentiated by the test for manganese (p. 159).

The mineral is found in veins accompanying metallic ores; and in nodules (ironstone or spathic iron) in clay and coal shales.

It is worked as an ore of iron.

54. Smithsonite ($ZnCO_3$) or **dry-bone ore** is an important ore of zinc. It occurs as druses, or coatings of tiny crystals, as botryoidal and stalactitic masses, as granular aggregates and as friable earth. Its crystals are commonly tiny rhombohedrons.

The mineral is white, gray, green or brown. It has a white streak, a vitreous luster, a hardness of 5 and a sp.gr. of 4.4. It is transparent or translucent.

When heated in the closed glass tube, CO_2 is driven off, leaving zinc oxide as a yellow residue, becoming white on cooling. It is infusible, but if moistened with

$Co(NO_3)_2$ solution and heated in the oxidizing flame, it becomes green. When heated on charcoal, a dense white vapor is produced. This settles on the cool parts of the charcoal as a yellow coating, changing to white upon cooling. If this be moistened with $Co(NO_3)_2$ and heated by the oxidizing flame, its color changes to green.

The reactions for zinc and its effervescence in hot acids distinguish smithsonite from all other compounds.

The mineral occurs in beds and veins in limestone and as crusts on other zinc minerals, and as porous masses on massive smithsonite (dry-bone ore). It is nearly always associated with galena (No. 9) and sphalerite (No. 10).

It is mined together with other zinc compounds as an ore of zinc.

55. Rhodochrosite ($MnCO_3$) differs from the other carbonates in its rose-red color when pure. It occurs in rhombohedral crystals, in cleavable masses and in granular aggregates. It is rose-red or brown, and transparent or translucent, and has a white streak and a vitreous luster. Its hardness is 4 and its density 3.5.

The mineral is infusible before the blowpipe, but when heated it decrepitates and changes color. When heated on charcoal its residue is usually magnetic. When treated in the borax bead, it colors the bead violet, and when fused with Na_2CO_3 on charcoal it yields a bluish-green manganate.

Pure rhodochrosite is easily distinguished from all other minerals but the manganese silicate, rhodonite, by its color and its reaction for manganese (p. 159). It is distinguished from rhodonite by its effervescence with hot acids. Impure varieties resemble some forms

of siderite (No. 53); but the two are differentiated by the manganese reaction.

Rhodochrosite occurs in veins with metallic ores.

It is used to a slight extent as an ornamental stone and as an ore of manganese.

56. Aragonite ($CaCO_3$) has the same empirical formula as calcite (No. 50), but it crystallizes in the orthorhombic system, either in acicular or tabular crystals (Fig. 36) or in several crystals grouped together (twinned) in such a way as to resemble hexagonal

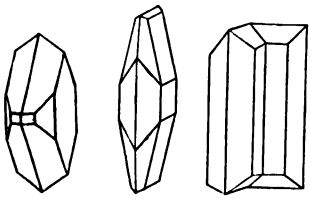


FIG. 36.—Aragonite Crystals.

FIG. 37.—Twinned Aragonite.

prisms (Fig. 37). It occurs also in globular masses in divergent bundles of fibers, in crusts, in stalactites and in massive forms.

The mineral has two cleavages. It is white, gray, green or some other light shade, and is transparent or translucent. It has a white streak and a vitreous luster. Its hardness is 3.5 to 4 and sp.gr. about 2.95.

Before the blowpipe, aragonite whitens and falls to pieces; otherwise, its reactions are like those of calcite.

It is distinguished from calcite (No. 50) by its cyrstallization, its cleavage, its sp.gr., and the reaction with $Co(NO_3)_2$ (p. 52).

The mineral occurs in beds with gypsum (No. 67) and as deposits from hot water.

It has no important uses.

57. Strontianite ($SrCO_3$), in general appearance, resembles aragonite (No. 56). It is found in acicular crystals, but more frequently in granular aggregates and massive.

It is white or some light shade, and is transparent or translucent. Its hardness is 3.5–4 and sp.gr. 3.7.

Before the blowpipe, it swells and colors the flame crimson. It dissolves in HCl, giving a solution from which a few drops of H_2SO_4 throws down a white precipitate, which imparts a crimson color to the blowpipe flame.

Strontianite is distinguished from all minerals but the carbonates by its effervescence in hot HCl, and is distinguished from the other carbonates by the color it imparts to the blowpipe flame.

It is the most common of all strontium compounds, and is the principal source of the strontium salts used in the arts. These are employed in refining beet sugar and in the preparation of "red fire".

The mineral occurs as veins in limestone and as an alteration product of other stronium compounds.

58. Witherite ($BaCO_3$) is similar to strontianite in appearance, but its crystals are more common (Fig. 38). It is much heavier, however, its sp.gr. being 4.3. Its hardness is 3 to 4.

The mineral dissolves in hot HCl. From this solution, H_2SO_4 throws down a white precipitate, which, when heated in the blowpipe flame, imparts to it a yellowish-green color.

Witherite is distinguished from the other carbonates by its sp.gr. and the green color it imparts to the blowpipe flame, especially after moistening with HCl.

It occurs mainly as veins in limestone.

It is a source of barium compounds, but is comparatively unimportant.

59. Cerussite ($PbCO_3$), a minor lead ore, occurs in crystals and in fibrous and granular masses. Its

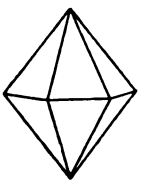


FIG. 38.—Witherite Crystal

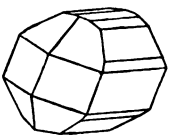


FIG. 39.—Cerussite Crystals.

FIG. 40.—Group of Cerussite Crystals.

simple crystals are prismatic (Fig. 39) or tabular and these are often grouped into bundles (Fig. 40) so as to produce six-rayed stars.

The mineral, when fresh, is white and vitreous, but its surface is frequently discolored by dark decomposition products. Its streak is white, its hardness 3–3.5 and its sp.gr. 6.5.

Cerussite is not easily confused with other minerals. It is well characterized by its high sp.gr. and its reactions for lead (p. 158). It is distinguished from anglesite (No. 65) by its effervescence with hot HCl.

Cerussite is found with other lead compounds in veins. It often coats galena (No. 9).

It is mined with galena and other lead minerals as an ore of lead.

Basic Carbonates

60. Malachite ($(CuOH)_2CO_3$), and azurite ($Cu(CuOH)_2(CO_3)_2$), are basic copper carbonates. Malachite is bright green and azurite bright blue.

Malachite occurs in fibrous, radiate, stalactitic, granular or earthy masses, or as druses of small crystals covering other copper minerals.

It is bright green in color and has a light green streak. It possesses a vitreous luster, but this becomes silky in fibrous masses and dull in massive specimens. Crystals are translucent and massive pieces opaque. Its hardness is 3.5–4 and its density about 4.

Malachite is fusible before the blowpipe. Heated with Na_2CO_3 it yields copper globules and tinges the flame green, but if moistened with HCl the color of the flame becomes azure-blue. When heated in the closed tube, it gives an abundance of water. It dissolves in hot HCl with effervescence, producing a solution which becomes purplish-blue on addition of an excess of $(NH_2)OH$.

Malachite is easily distinguished from all other minerals, but some varieties of turquoise (No. 78) and *atacamite* ($Cu_2(OH)_3Cl$), by its color. From these it is distinguished by its effervescence with acids.

The mineral is a decomposition product of other copper compounds. It occurs in the upper portions of veins of copper ores, where it is associated with azurite (No. 61), copper (No. 4), cuprite (No. 35), limonite (No. 45) and the sulphides of iron and copper.

It is mined with other copper compounds as an ore of the metal. Massive and fibrous forms are employed as ornamental stones for inside decoration, and are sawn into slabs and polished for use as table tops, clock cases, etc.

61. Azurite ($Cu(CuOH)_2(CO_3)_2$) is more often found in crystals than is malachite. It occurs also as incrustations and in massive and earthy forms, associated with malachite.

The mineral is dark-blue, vitreous and translucent or transparent. Its streak is light blue. It is brittle and has a hardness of 3.5–4 and a sp.gr. of 3.8.

Its blowpipe and other characteristic reactions are the same as those for malachite. By these it is easily distinguished from all other blue minerals.

Azurite is associated with malachite in all of its various types of occurrence.

Its uses are the same as those of the green carbonate.

SULPHATES

The sulphates of greatest importance are those of the alkaline earths and lead. Of these, three are anhydrous and one is hydrous. All yield the sulphur reaction with $NaCO_3$ (p. 146).

Anhydrous Sulphates

62. Anhydrite ($CaSO_4$) rarely occurs in crystals. It is usually in granular, fibrous, and lamellar masses of a white, gray, bluish or reddish color, and a white streak. It is translucent or opaque and has a vitreous or pearly luster. Its hardness is 3–3.5 and sp.gr. 2.9–2.98, and it cleaves in three perpendicular directions.

Before the blowpipe, anhydrite fuses to a white enamel and colors the flame red. When fused with soda on charcoal for a long time, it forms a sulphide which stains silver. It is slowly dissolved in acid. In the presence of moisture, it gradually changes to gypsum (No. 67).

Anhydrite is distinguished from most other white and light-colored minerals by the reaction for S and the red color it imparts to the flame. It is differentiated from celestite (No. 64) by its sp.gr.

The mineral occurs in beds with rock salt, limestone and gypsum.

When cut and polished it is used as an ornamental stone. It is mixed with gypsum and used as land plaster.

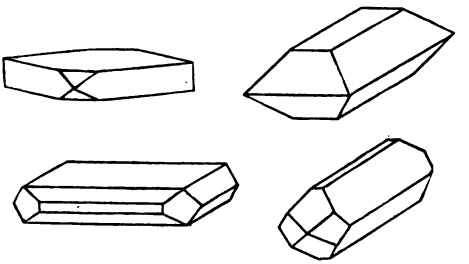


FIG. 41.—Barite Crystals.

63. Barite ($BaSO_4$) or **heavy spar** usually occurs in crystals, though it is also found massive and in granular, fibrous and lamellar forms.

Its crystals are usually tabular or prismatic (Fig. 41) and they possess two good cleavages.

The mineral is white, yellow, brown, blue or red; its streak is white and its luster vitreous. It is transparent or opaque and brittle. Its hardness is 3 and sp.gr. 4.5.

Before the blowpipe, barite decrepitates and fuses, at the same time coloring the flame yellowish-green. The fused mass reacts alkaline to litmus paper. When heated with Na_2CO_3 on charcoal for some time, the fused mass, placed on silver and moistened with a drop of water, produces a black stain. The mineral is insoluble in water and acids.

It is distinguished from all other minerals by its high sp.gr., its reaction for sulphur, and the color it imparts to the blowpipe flame.

Barite is a common vein stone associated with copper, lead and silver ores. It occurs also as nodules in clay produced by the weathering of limestone.

The white varieties are ground and used as pigments. They are also employed in the manufacture of paper, oilcloth, enameled ware, in refining sugar and in the manufacture of barium salts. The colored, massive varieties are sawed into slabs and used as ornamental stones.

64. **Celestite** ($SrSO_4$) occurs in tabular or prismatic crystals (Fig. 42), and in fibrous and in globular masses.

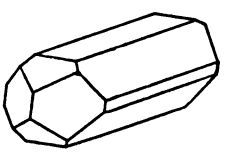


FIG. 42.—Celestite Crystals.

The mineral is usually white and transparent or translucent, but sometimes it has a light blue tinge. It possesses two cleavages. Its hardness is about 3 and its sp.gr. about 3.9. Its luster and streak are like those of barite.

Before the blowpipe, celestite reacts like barite, except that it tinges the flame crimson. It is insoluble in water and acids.

Celestite is easily distinguished from all minerals

but the sulphates by its appearance and its reaction for sulphur. It is distinguished from the other sulphates by its sp.gr. and the crimson color it gives to the flame.

It occurs in beds with rock salt (No. 27) and gypsum (No. 67), in groups of crystals associated with sulphur (No. 3), and as isolated crystals in limestone. It is found also in massive veins.

It is used to some extent as a source of strontium compounds.

65. Anglesite ($PbSO_4$) occurs principally as complicated crystals (Fig. 43), associated with galena (No. 9) and other ores of lead, but it is found also massive and in granular, stalactitic and globular forms. Its crystals are usually prismatic. They possess two cleavages.

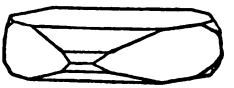


FIG. 43.—Anglesite Crystal.

The mineral is white, gray or colorless, and its surfaces are often tarnished with a gray coating. It is transparent and brittle, has a white streak and a vitreous or resinous luster. Its hardness is 2.5 to 3 and its sp.gr. 6.3.

When heated before the blowpipe, the mineral decrepitates. It fuses in the flame of a candle. If heated on charcoal with the reducing flame, it effervesces and yields a globule of metallic lead. It also readily gives the sulphur reaction (p. 146). It dissolves in HNO_3 with difficulty.

Anglesite is characterized by its high sp.gr. and its reactions for lead and sulphur.

It is found in crystals implanted on galena and other lead minerals and sometimes as the filling of veins.

It is mined with other minerals as an ore of lead.

66. Alunite ($K(Al(OH)_2)_3(SO_4)_2$) usually occurs in tabular crystals, in compact and crystalline masses and in aggregates, composed of particles of the mineral and silicious materials, forming a hard, granular, nearly white rock.

Alunite is white, gray or pink, and has a white streak. It is translucent and has a vitreous or porcelain-like luster. Its hardness is 3.5–4 and its sp.gr. 2.6–2.75.

Before the blowpipe it decrepitates but is infusible. In the closed tube it yields water. With the proper treatment it reacts for aluminium (p. 147) and sulphur (p. 146). It is soluble in hydrochloric acid.

If differs from gypsum (No. 67) by its greater hardness and from anhydrite (No. 62) by its infusibility and the color it imparts to the flame. From aragonite and magnesite (Nos. 56, 52), it is distinguished by the test for CO_2 (p. 149), and from chert (p. 192) by its inferior hardness.

Alunite is commonly found in veins cutting volcanic rocks. It has been utilized as a source of alum and is now being mined as a source of aluminium and potassium. Massive varieties are used for millstones.

Hydrated Sulphates

67. Gypsum ($CaSO_4 \cdot 2H_2O$) is the most important of all the sulphates. It is far more common than the corresponding anhydrous compound, anhydrite ($CaSO_4$), (No. 62). It occurs in massive beds associated with limestone and rock salt, in finely granular aggregates, in fibrous groups, and in crystals. The

crystals are well-characterized, monoclinic forms (Fig. 44) with a tabular habit, which are often twinned in such a way as to produce swallow-tail or arrow-shaped pairs.

The mineral is white, or colorless, and transparent or translucent when pure; gray, red, yellow, blue or black when impure. It possesses one good cleavage, yielding thin inelastie foliæ. The luster is pearly on cleavage surfaces and vitreous on all others. Massive

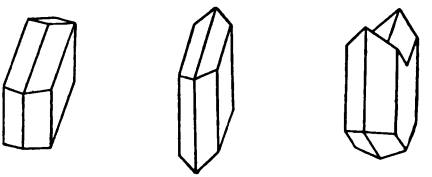


FIG. 44.—Gypsum Crystals.

varieties are dull. The mineral has a hardness of only 1.5–2 and a sp.gr. of 2.32.

In the closed glass tube, gypsum yields abundant water and falls into a white powder which reacts alkaline. It colors the blowpipe flame yellowish-red and yields the sulphur test on a silver coin. It is slightly soluble in water and readily soluble in HCl. When heated to 250° it loses water and disintegrates into powder, which when ground becomes "plaster of Paris". This, when moistened with water, again combines with it and crystallizes into an aggregate of interlocking crystals. This process constitutes the "set."

Gypsum is distinguished from other easily cleavable, colorless minerals by its softness, and the reaction for sulphur (p. 146).

The varieties of gypsum generally recognized are:

Selenite, the transparent, crystallized variety.

Satin spar, a finely fibrous variety.

Alabaster, a fine-grained granular variety.

Rock-gypsum, a massive, structureless, often impure and colored variety.

Gypsite is gypsum mixed with earth.

Gypsum occurs in numerous beds interstratified with limestone, clay and halite, and as crystals embedded in limestone, clay or sand, or implanted on the rocks around volcanic vents. It is found also as gypsite in hills of wind-blown sand.

Crude gypsum is used in the manufacture of plaster, as a retarder in Portland cement, and as a fertilizer, under the name of *land plaster*. The calcined mineral is used as plaster of Paris and in the manufacture of finishing plasters, and certain kinds of cements. Alabaster is a medium for sculpture.

TUNGSTATES, MOLYBDATES AND CHROMATES

The tungstates are salts of tungstic acid, H_2WO_4; the molybdates, salts of molybdic acid, H_2MoO_4; and the chromates, salts of chromic acid, H_2CrO_4.

68. Scheelite ($CaWO_4$) is one of the most important ores of tungsten. It occurs in granular and globular masses and in tetragonal pyramidal crystals (Fig. 45).

The mineral is white, yellow, brown, greenish or reddish, with a white streak and a vitreous luster. It has one distinct cleavage and an uneven break. It is brittle, has a hardness of 4.5–5, and a sp.gr. of about 6. It is transparent or translucent.

Before the blowpipe, scheelite fuses to a semi-transparent glass. Heated with borax it forms a

transparent glass, which becomes opaque on cooling. With microcosmic salt it gives the characteristic blue beads for tungsten (p. 141), but specimens containing iron must first be heated with tin on charcoal before the blue bead can be produced. It is soluble in HCl and HNO_3 with the production of a yellow powder (WO_3), and solutions which give the characteristic tungsten reaction (p. 165).

Massive scheelite is distinguished from limestone by its higher sp.gr. and the absence of effervescence with HCl. It is distinguished from quartz by its

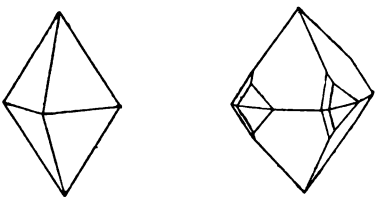


FIG. 45.—Scheelite Crystals.

softness and from barite by its greater hardness, and from both by its higher sp.gr.

The mineral is found in veins associated with topaz, fluorite, molybdenite, wolframite (Nos. 91, 29, 8, 69), and many metallic ores.

It is mined as an ore of tungsten, which is used principally in the manufacture of tool steel. The metal is employed also as filaments in incandescent lamps and in the manufacture of sodium tungstate, which is used for fire-proofing cloth. Its salts are used as mordants in dyeing, and for a number of minor purposes.

69. Wolframite ($(Fe,Mn)WO_4$) is the name given to a series of compounds that are mixtures of $FeWO_4$

and $MnWO_4$, which when pure are known as *ferberite* and *huebnerite*.

Wolframite occurs in prismatic crystals (Fig. 46), which have one perfect cleavage, and in lamellar and granular masses.

Huebnerite is black or brownish-red and translucent. Wolframite is black and translucent on very thin edges, and ferberite is black and opaque. The streak of huebnerite is yellow or yellowish-brown; of ferberite, brown or brownish-black; and of wolframite, yellowish-brown or brown.

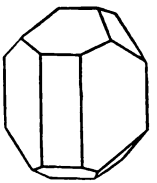


FIG. 46.
Wolframite Crystal.

Before the blowpipe, wolframite fuses to a globule that is magnetic. Fused with soda and niter on platinum, it gives a bluish-green manganate. It dissolves in aqua-regia with the production of the yellow WO_3, and when treated with H_2SO_4 and tin it yields the blue tungsten reaction (p. 165).

Wolframite is distinguished from columbite (No. 79), samarskite (No. 81) and uraninite (No. 84) by its more perfect cleavage and its reactions with the beads. It is distinguished from black tourmaline (No. 108) by the difference in sp.gr.

The mineral usually occurs in veins with tin ores, and as grains and crystals in coarse-grained granites.

Wolframite (including huebnerite and ferberite) is the most important source of tungsten.

70. Wulfenite ($PbMoO_4$) occurs principally in thin, tabular crystals (Fig. 47) implanted on minerals and the walls of cracks and pores in veins of lead ores.

The mineral is orange, olive, gray, brown, bright red or colorless. It is brittle and transparent. Its streak is white, its luster resinous or adamantine. Its hardness is 3, and sp.gr. 6.8. It has a very smooth cleavage parallel to the faces of a pyramid.

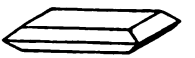


FIG. 47.
Wulfenite Crystal.

Before the blowpipe, wulfenite decrepitates and fuses easily. Heated with Na_2CO_3 on charcoal it gives lead globules. It gives also the usual reactions for molybdenum (p. 160). It is decomposed on evaporation with HCl, yielding lead chloride and molybdic oxide. This when placed in a little water and treated with zinc turns blue.

Wulfenite is distinguished from vanadinite (No. 75) by crystallization, by the test for chlorine (vanadinite), and the blue solution test for molybdenum (p. 149).

The mineral is an important source of molybdenum.

71. Crocoite ($PbCrO_4$) occurs in hyacinth-red granular masses and in small prismatic crystals implanted on the walls of cracks in rocks.

Its color is usually bright red and its streak orange-yellow. It is translucent and sectile. Its hardness is 2.5–3, and its density about 6.

In the closed tube it decrepitates and blackens, but it reassumes its original color on cooling; on charcoal it deflagrates and fuses easily, yielding a lead globule and sublimate. With microcosmic salt it gives the green bead of chromium (p. 141). The mineral dissolves in HCl, yielding a solution which upon the addition of tin turns apple-green, then brownish, and finally red.

[illegible] is easily distinguished from vanadinite [illegible] by the test for chlorine (p. 134), and from wulfenite No. [illegible] by the tests for molybdenum (p. 149) and chromium (p. 142).

[illegible] of little commercial value.

PHOSPHATES, ARSENATES AND VANADATES

The normal phosphates are salts of the acid H_3PO_4, the normal arsenates of the corresponding H_3AsO_4, and the normal vanadates of H_3VO_4. Some minerals are normal salts, but the greater number are basic, and of double salts, and many are hydrated. The most important are the members of the apatite group.

Anhydrous Phosphates, Arsenates and Vanadates

APATITE GROUP

72. Apatite $Ca_5Ca(Cl,F)(PO_4)_3$ is the most common of all the phosphates. It occurs in crystals, in massive, granular and fibrous forms and in globular masses.

Its crystals are hexagonal prisms or pyramids, or a combination of the two (Fig. 48). Their habit is usually prismatic.

FIG. 48.—Apatite Crystals.

Apatite is colorless, white, green or brown, and transparent, or opaque. It has a white streak, a vitreous luster, a hardness of 4.5–5, and a sp.gr. of 3.2.

Before the blowpipe it fuses with difficulty, coloring the flame yellowish-red. When moistened with H_2SO_4 and heated, the flame is tinged a bluish green (phos-

phoric acid). Some specimens react for chlorine with copper oxide (p. 154), others for fluorine (p. 155). If fused with a little piece of magnesium ribbon a phosphide is produced, which, when moistened with water, gives the odor of moist phosphorus. The mineral dissolves in HCl and HNO_3.

Apatite is easily recognized by its crystals and the test for phosphorus. It is distinguished from beryl (No. 103) by its greatly inferior hardness, and from calcite by the fact that it does not effervesce in acids.

The varieties recognized by distinct names are:

Ordinary apatite, crystals or granular masses.

Mangan-apatite, in which Mn partially replaces the Ca of ordinary apatite. This is dark bluish-green.

Phosphorite, fibrous, concretionary apatite.

Phosphate rock is a mixture of apatite, phosphorite and various hydrated phosphates often mixed with bones, teeth, etc. It is, properly, a rock with a brecciated and concretionary structure.

Apatite occurs in igneous and sedimentary rocks, in veins with magnetite and cassiterite, and in beds (phosphate rocks).

The mineral is used principally in the manufacture of fertilizers.

73. Pyromorphite ($Pb_4(PbCl)(PO_4)_3$) occurs principally as small crystals implanted on the walls of cracks and cavities in rocks, and as globular, granular and fibrous masses.

Its crystals are similar to those of apatite, but are often rounded on their edges and sometimes are skeletons (Fig. 49).

Pyromorphite is gray, white, or orange, but more commonly green, yellow or brown. Its streak is white, its luster resinous, its hardness 3.5–4, and its sp.gr. about 7. It is translucent and brittle.

FIG. 49.—Skeleton Crystal of Pyromorphite.

When heated in the closed glass tube, the mineral fuses and gives a white sublimate of lead chloride. It colors the blowpipe flame bluish-green. When fused on charcoal, it melts to a globule which crystallizes on cooling and yields a coating which is yellow (PbO) near the assay, and white ($PbCl_2$) at a distance from it. It yields also the other reactions for lead (p. 158), and those for chlorine (p. 154) and phosphorus (p. 161). The mineral is soluble in acids.

Pyromorphite is easily recognized by its forms, high sp.gr. and its action when heated on charcoal.

It occurs principally in veins with other lead ores.

It possesses no commercial value, except as it is mined with other minerals as an ore of lead.

74. Mimetite ($Pb_4(PbCl)(AsO_4)_3$) is very much like pyromorphite in appearance and manner of occurrence, and in most of its properties. It is usually, however, a little lighter in color and its sp.gr. is a little greater (7–7.2).

It fuses more easily than pyromorphite (No. 73), and when heated on charcoal it yields arsenical fumes. This distinguishes it from the phosphate.

The mineral is not as common as pyromorphite. It occurs in veins with other lead minerals and is mined with them as an ore of lead.

75. Vanadinite ($Pb_4(PbCl)(VO_4)_3$) is easily recognized by its bright red prismatic crystals (Fig. 50), implanted on the walls of cracks and crevices in rocks or on the surfaces of other minerals. It occurs also in globular masses and in crusts.

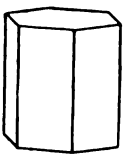


FIG. 50. Vanadinite Crystal.

Its crystals are usually small hexagonal prisms that show hollow faces. Often they are grouped in little pyramids.

Vanadinite is brittle. It has a hardness of about 3 and a sp.gr. of about 7. Its luster is resinous, and its color ruby-red, brownish-yellow or reddish-brown. Its streak is white or yellow. It is translucent or opaque.

Heated in the closed glass tube, vanadinite decrepitates; on charcoal it fuses easily to a black lustrous mass which, upon further heating in the reducing flame, yields globules of lead and a white sublimate of $PbCl_2$. After complete oxidation of the lead by heating with the oxidizing flame on charcoal, the residue gives an emerald-green bead in the reducing flame with microcosmic salt (p. 141). The mineral also gives the test for chlorine (p. 154). It is soluble in HCl. The addition of metallic tin to this solution will cause it to turn blue (p. 166) in consequence of the reduction of the vanadium compounds by nascent hydrogen. Some specimens also give the test for arsenic (p. 151). When vanadium and arsenic are present in nearly equal quantities, the substance is known as *endlichite*.

Vanadinite is easily distinguished from most other minerals by its color. It is distinguished from wulfenite (No. 70) by the shape of its crystals and the reac-

tions for chlorine and vanadium; and from crocoite (No. 71) by the tests for chromium and chlorine.

The mineral occurs principally in regions of volcanic rocks.

It is an important source of vanadium, which is employed in the manufacture of certain grades of steel and bronze. Its compounds are used as pigments and mordants.

Hydrated Phosphates and Arsenates

76. Wavellite ($(Al(OH,F))_3(PO_4)_2 \cdot 5H_2O$) is one of the commonest of hydrated phosphates. It rarely

FIG. 51.—Radiating Groups of Wavellite Crystals on a Rock Surface.

occurs in crystals. It is usually in globular or radiating groups of fibers (Fig. 51).

The mineral is vitreous in luster, translucent and white, green, yellow, brown or black. Its streak is white. It is brittle, infusible and insoluble. Its hardness is 3.5 and density 2.3.

Heated in a closed glass tube, wavellite yields water, the last traces of which react acid and often etch glass (HF). In the blowpipe flame it swells and breaks into tiny infusible fragments, at the same time tinging the flame green. It is soluble in HCl and H_2SO_4. When heated with H_2SO_4 many specimens yield HF, which etches glass. If heated moistened with $Co(NO_3)_2$ solution and again heated, the mineral turns blue.

Wavellite is distinguished from turquoise (No. 78) by its action in the blowpipe flame, by its inferior hardness and its manner of occurrence.

The mineral is usually found as radiating bundles of fibers on the walls of cracks in rocks and as globular masses filling their pores and larger cavities.

It has no economic value.

77. Erythrite ($Co_3(AsO_4)_2 \cdot 8H_2O$) is not a common mineral, but it is included here because, being an alteration product of other cobalt compounds, it is an important indicator of the presence of cobalt ore. It is easily recognized by its rose-red color.

It usually occurs in slender prismatic crystals arranged in divergent and irregular groups, in crusts, or in earthy masses. It possesses one perfect cleavage.

It is transparent or translucent; has a gray, crimson, rose-red or peach-red color and a white or pink streak. Its hardness varies between 1.5 and 2.5, and its sp.gr. is 2.95. Its luster is pearly on cleavage planes and vitreous on other surfaces. It is flexible and sectile.

Heated in the closed glass tube, erythrite turns blue and yields water at a low temperature. At a high temperature it produces a dark sublimate. In the blowpipe flame it fuses easily and tinges the flame

pale blue. On charcoal it fuses and yields arsenic fumes and a gray globule which colors the borax bead deep blue (p. 141). It is soluble in HCl, producing a pink solution, which upon evaporation to dryness gives a blue stain.

Erythrite is easily recognized by its color and cobalt reactions. From pink tourmaline (No. 108) it is distinguished by hardness and easy fusibility.

The mineral is found principally in veins of cobalt ores, more particularly near the surface, where it sometimes occupies the entire width of the veins.

It usually accompanies other cobalt minerals in small quantity and is mined with them as an ore of cobalt. Its principal importance arises from the fact that it is a surface indication of the presence beneath of more important cobalt ores.

78. Turquoise ($6(Al(OH)_2)\cdot CuOH\cdot H_5(PO_4)_4$) may be an acid phosphate, that is, a phosphate in which some of the H of the acid has not been replaced by bases. It is more likely, however, a mixture of $(Al(OH)_2)_2HPO_4$ and $(CuOH)_2HPO_4$.

Crystals are extremely rare. As usually found, the mineral is an amorphous or cryptocrystalline translucent material with a waxy luster and a sky-blue, green or greenish-gray color, and a white streak. Its fracture is conchoidal, its hardness 6, and its sp.gr. 2.7. It is brittle.

In the closed glass tube it decrepitates, yields water, and turns black or brown. It is infusible, but it assumes a glassy appearance when heated, and colors the flame green. When moistened with HCl and again heated the flame is tinged with the azure blue of copper chloride. The mineral is soluble in HCl.

Turquoise is usually easily recognized by its color, its hardness and its reactions for water and copper.

It is found in narrow veins and irregular masses in certain brecciated volcanic rocks.

It is an important gem stone. Small pieces of rock containing tiny veins of the mineral are polished and used under the name *turquoise matrix.*

COLUMBATES AND TANTALATES

The commonest columbates and tantalates are salts of the meta acids $H_2Cb_2O_6$ and $H_2Ta_2O_6$, the relations of which to the normal acids are indicated by the equation: $2H_3CbO_4 - 2H_2O = H_2Cb_2O_6$.

79. Columbite ($(Fe,Mn)Cb_2O_6$) and **(80.) Tantalite** ($(Fe,Mn)Ta_2O_6$) are the names given to the nearly

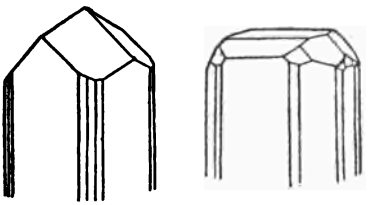


FIG. 52.—Columbite Crystals.

pure columbates and tantalates of iron and manganese. So rarely, however, are these compounds found pure that the name columbite usually refers to their mixtures.

Columbites occur mainly in short prismatic crystals (Fig. 52) in coarse granite dikes.

The minerals are usually opaque, black and lustrous, though occasionally brown and translucent. Their streak is black or brown. They possess one distinct

cleavage. Their hardness is 6, and sp.gr. between 5.3 and 7.3, increasing with the proportion of Ta present.

The minerals are not affected by the blowpipe. When columbite is decomposed by fusion with KOH and the result of the fusion is dissolved in HCl and H_2SO_4 this solution turns blue on the addition of metallic zinc. The mineral is also partially decomposed when evaporated to dryness with H_2SO_4, forming a white compound that changes to yellow. This residue boiled with HCl and zinc turns blue. Tantalite is decomposed by fusion with $KHSO_4$ on platinum. This, when heated with dilute HCl yields a yellow solution and a heavy white powder. Upon the addition of zinc the powder becomes blue. The color disappears on the addition of more water.

Columbite may easily be confused with black tourmaline (No. 108), ilmenite (No. 132), and wolframite (No. 69). From tourmaline it is distinguished by crystallization, by high sp.gr. and luster; from wolframite by less perfect cleavage and the reaction with aqua-regia and from ilmenite by the test for titanium (p. 164).

Tantalite has a slight value as a source of tantalum, which is used for filaments in certain types of incandescent lamps. Columbite has no value.

81. Samarskite and (**82.**) **Yttrotantalite** are complicated mixtures of yttrium, erbium, cerium, thorium and other salts of pyrocolumbic and pyrotantalic acids ($H_4Cb_2O_7$ and $H_4Ta_2O_7$) which are related to the normal acids as follows: $2H_3CbO_4 - H_2O = H_4Cb_2O_7$. The compound in which the columbates predominate is samarskite; that in which the tanta-

lates are in excess is yttrotantalite. They can be distinguished from one another only by analysis.

The minerals are usually massive, but occasionally they occur in prismatic crystals (Fig. 53). Samarskite is velvety black, opaque and brittle. Its streak is reddish-brown, its hardness 5 to 6, and its sp.gr. 5.7. Yttrotantalite is black, brown or yellow. Its luster is submetallic or vitreous; its streak gray to colorless; its hardness 5–5.5; and its sp.gr. 5.5–5.9. Some specimens are opaque and others translucent.

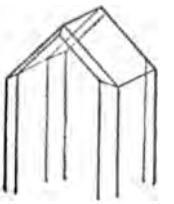


FIG. 53.—Samarskite Crystals.

The reactions of both minerals are extremely complex because of the great number of elements usually present in them. They always yield, however, the blue-solution test for columbium (p. 155) or tantalum (p. 163), and most specimens react for Mn, Fe, Ti and U. The test for U is an emerald-green bead with microcosmic salt in both oxidizing and reducing flames. Both minerals affect the photographic plate.

The two minerals are distinguished from wolframite, columbite, and tantalite (Nos. 69, 79, 80) by the forms of their crystals and by the lack of a distinct cleavage. Samarskite is easily recognized by its velvety black luster.

Both minerals occur in coarse granite veins.

Neither mineral is at present of any commercial value. Both are, however, extremely interesting as the sources of many of the rare elements; and, especially, as a possible source of radium.

URANYL COMPOUNDS

The most important compounds of uranium contain this element in the form of the radical uranyl (UO_2). They are very complex in composition and are of great interest because of their content of uranium, an element which appears to be genetically related to radium. The two prominent sources of uranium and radium are the vanadate, carnotite, and the uranate, uraninite.

83. Carnotite ($(Ca,K_2)(UO_2)_2(VO_4)_2 \cdot H_2O$) is so complex that the formula given is merely suggestive. It appears to be a mixture of several vanadates in which the potassium uranyl vanadate is most prominent. Many specimens contain also As, P, Si, Ti, Mo, Fe, Al, Pb, Cu, Ca, Ba, K and other elements.

The mineral has been found in tiny yellow crystalline grains and powder in the interstices between the grains of sandstones and conglomerates, and as nodules and lumps in these rocks. With a decrease in the proportion of U present its color becomes duller, and with increase in vanadium it gradually changes to olive-green and finally to brick-red. The color of the streak is paler than that of the mineral.

At a moderate heat carnotite becomes black and melts. With microcosmic salt and a little Na_2CO_3 it fuses to a clear glass, which when cold is bright green. The mineral is soluble in HNO_3. If to the solution hydrogen peroxide be added, it will become brown. Moreover, the mineral yields all the reactions for vanadium (p. 166). It is radioactive.

Carnotite is one of the main sources of radium and uranium and is one of the sources of vanadium. Al-

though it contains a notable quantity of uranium, it has little value as an ore of this metal, because of the few uses to which uranium is put. This metal is used to some extent in making steel alloys and in the manufacture of iridescent glazes and glass. Its compounds are used in certain chemical determinations and as medicines, in photography, as porcelain paint, and as a dye in calico printing. The uses of vanadium have been referred to elsewhere (p. 74). Radium, because of its scarcity and its possible value as a therapeutic agent, has a selling price of about $2,000,000 per ounce in the form of the chloride. As the quantity of this element present varies with the quantity of uranium, the price of the ore is based on its percentage of U_3O_8. Carnotite containing 2 per cent. U_3O_8 and 5 per cent. V_2O_5 was quoted in 1913 at $1.25 per pound.

84. Uraninite or **pitchblende** (U_3O_8) is the only important source of radium besides carnotite. It is an extremely complicated mixture of UO_2, UO_3, ThO_2 and PbO with small quantities of ZrO_2, CeO_2, La_2O_3, Di_2O_3, Y_2O_3, Er_2O_3, MnO, CuO, and many other oxides, besides helium, argon and radium. It may be regarded as a uranyl-uranate, $(UO_2)_2UO_4$, in which Pb, Th and other basic elements replace a part of the UO_2.

Uraninite is found in cubic crystals and in crystalline and botryoidal masses. Crystals are rare.

The mineral is gray, brown or black and opaque. Its streak is brownish-black, gray or olive-green and its luster pitch-like or dull. Its fracture is conchoidal; its hardness 5.5; and its sp.gr. 9 to 9.7. It is brittle. Like other uranium compounds, it is radioactive.

Before the blowpipe it is infusible. Some specimens color the flame green (Cu). With borax it gives a yellow bead in the oxidizing flame, turning green in the reducing flame. All specimens give reactions for lead and many for S and As. Uraninite is soluble in HNO_3 and H_2SO_4 with slight evolution of helium, the ease of solubility increasing with increase in the proportion of rare earths present. If roasted, mixed with Na_2CO_3 and KNO_3 and fused, and then treated with HCl, a yellow powder will be produced after a few minutes, and this will change to scarlet on being heated.

Uraninite is distinguished from wolframite (No. 69), columbite (No. 79) and tantalite (No. 80) by lack of cleavage, and from these minerals and samarskite (No. 81) by its greater sp.gr. and by differences in crystallization.

Uraninite occurs in coarse granite dikes, and in veins with ores of silver, lead, copper and other metals. It is mined as a source of uranium and radium. Its uses are described in the section on carnotite (No. 83).

SILICATES

The silicates are salts of the various silicon acids, H_4SiO_4, H_2SiO_3, $H_2Si_2O_5$, $H_4Si_3O_8$, etc. They include the most common minerals and those that occur in greatest quantity. They make up the greater portion of the earth's crust, forming most of the rocks and a large portion of the vein fillings. In number they exceed all other minerals, but because of their stability, only a few are of any commercial importance, except in the form of their aggregates, the siliceous rocks, and as the sources of their disintegration products.

As in the case of other compounds, there are silicates that contain H and O in such relations to their other components that, when heated, they yield water. In some cases, this water is given off at a comparatively low temperature and the compound is called a hydrate, or is said to contain water of crystallization. In other cases, the water is formed only at a high temperature. In these instances, it is said to be combined and the compound is usually basic.

Anhydrous Silicates

85. Olivine ($(Mg,Fe)_2SiO_4$) is the name of mixtures of Mg_2SiO_4 and Fe_2SiO_4, which occur nearly pure under the names *forsterite* and *fayalite*. Only the mixture, olivine, is common.

This occurs in small prismatic crystals and grains and in granular aggregates, mainly in igneous rocks.

It is yellowish-green, glassy and transparent. Its streak is white, its cleavage distinct in one direction, its hardness between 6.5 and 7, and its sp.gr. 3.27–3.37. The sp.gr. of forsterite is about 3.25 and of fayalite, 4.1.

Before the blowpipe olivine whitens but does not fuse, except in the case of varieties rich in iron. These fuse to a magnetic globule. All the olivines are decomposed by strong HCl and H_2SO_4 with the separation of gelatinous silica.

Olivine is easily recognized by its luster, its color and its solubility in acids.

It occurs as an original constituent of basic igneous rocks and as a metamorphic product in dolomitic limestones. It is also present as rounded grains in some meteorites.

Olivine alters easily to a mixture of iron oxides and fibrous or scaly gray or green serpentine (No. 104), according to the reaction, $2Mg_2SiO_4+2H_2O+CO_2 = H_4Mg_3Si_2O_9+MgCO_3$.

The only member of the group that is of any economic importance is a pale, yellowish-green, transparent olivine, which is used as a gem under the name *peridot*.

86. Willemite ($ZnSiO_4$) is an important ore of zinc at a few places. It occurs in prismatic hexagonal crystals (Fig. 54), in grains, and massive.

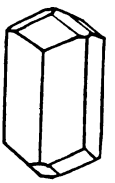


Fig. 54. Willemite Crystal.

Nearly all willemite contains some manganese. When this is in notable quantity (5–7 per cent of MnO) the variety is known as **Troostite** (**87.**).

Willemite is colorless, yellow, brown, blue or black, while troostite is green, yellow, gray or brown. Colored varieties are translucent, but colorless willemite is transparent. Both are vitreous. Their hardness is between 5 and 6, and their sp.gr. between 3.9 and 4.3.

Both minerals glow when heated before the blowpipe, and fuse with difficulty. Both gelatinize with HCl. Willemite reacts for Zn with $Co(NO_3)_2$ on charcoal (p. 147) and troostite gives in addition the reactions for Mn (p. 159).

Willemite and troostite are easily recognized by their crystals and the reactions for zinc and manganese.

Willemite occurs in veins with other zinc compounds, but in small quantities only, except at Franklin Furnace, N. J., where it occurs with troostite in large quantities, associated with franklinite (No. 49) and the zinc oxide, zincite (No. 36).

Both are mined with the last-named mineral as an ore of zinc.

88. Garnet ($R''_3R'''_2(SiO_4)_3$) is the name given to a series of compounds of the general formula indicated. In this, R″=Ca, Mg, Fe and R‴=Al, Fe, Cr. Certain of the compounds have been given names of which the following are the most common:

Grossularite or *Hessonite*	$Ca_3Al_2(SiO_4)_3$	White, cinnamon, pale green or red
Pyrope	$Mg_3Al_2(SiO_4)_3$	Deep red or black
Spessartite	$Mn_3Al_2(SiO_4)_3$	Yellow, brownish-red
Almandite	$Fe_3Al_2(SiO_4)_3$	Red, brown or black
Andradite or *Melanite*	$Ca_3Fe_2(SiO_4)_3$	Black, brown, green or yellow
Uvarowite	$Ca_3Cr_2(SiO_4)_3$	Emerald green

Garnets nearly always occur in isometric crystals (Fig. 55) or in round grains. They vary in color

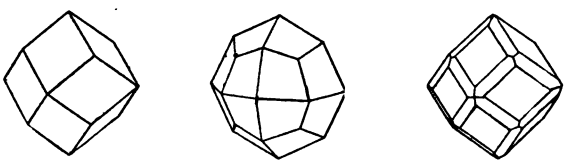


FIG. 55.—Garnet Crystals.

according to composition (see above), the commonest color being reddish-brown. Their luster is vitreous; streak, white; hardness, 6–7.5; and sp.gr., 3.4–4.3. They are translucent or transparent.

All, except uvarowite, fuse fairly easily to a brown or black glass or globule, which in the case of almandite and melanite is magnetic. Uvarowite is infusible. Some garnets are unattacked by acids; others are

partially decomposed. After ignition, all but uvarowite are decomposed by HCl, with the separation of gelatinous silica in most cases.

When in crystals, garnets are easily distinguished from most other minerals by their forms, color and hardness. White garnets are distinguished from leucite (No. 101) and from analcite (No. 130) by their greater hardness and their insolubility in acids. Massive garnet may resemble vesuvianite (No. 109), zircon (No. 89), sphene (No. 131) or tourmaline (No. 108). It is distinguished from zircon by its inferior hardness, from tourmaline by its higher sp.gr., from sphene by the reaction for Ti, and from vesuvianite by its lower sp.gr.

When exposed to the atmosphere, garnets may be partially or entirely changed to epidote (No. 92), muscovite (No. 96), chlorites (No. 100) or serpentine (No. 104), and, consequently, their surfaces may be covered with films of these substances, which will hide their true color and hardness.

Garnets occur in all rocks and in many quartz and ore veins.

The varieties that are transparent are used as gems, especially pyrope, almandite and grossularite. Others are crushed and employed as abrasives.

89. Zircon ($ZrSiO_4$) is nearly always in crystals (Fig. 56), though it is known also in granular masses, in irregular lumps and as rolled pebbles. Its crystals are usually square prisms terminated by four-sided pyramids.

It is commonly colored brown, reddish, gray or yellow, but in rare cases is colorless. Its streak is always white. It is transparent or translucent and

sometimes opaque. Its luster is glossy, its hardness 7.5 and sp.gr. 4.7.

Before the blowpipe, it loses color, but is infusible and frequently becomes white. It is insoluble in acids and alkalies.

It is distinguished by its crystallization, hardness and infusibility.

Zircon is a frequent constituent of rocks, of veins and of river deposits.

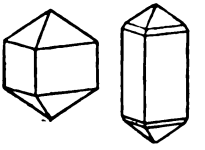


FIG. 56.—Zircon Crystals.

The mineral is used as a source of zirconia, which is employed in incandescent lamps; and red and brown transparent varieties are utilized as gems under the name of *hyacinth*.

90. Andalusite ($Al(AlO)SiO_4$) is a characteristic metamorphic mineral. It occurs principally as a component of shales that have been intruded by

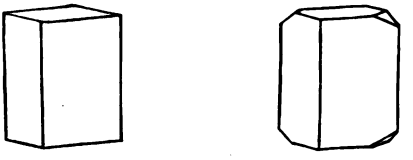


FIG. 57.—Andalusite Crystals.

igneous rocks. It is found in crystals and in massive and granular forms.

Crystals are usually simple and columnar in habit (Fig. 57) and they possess good cleavages in two directions.

Andalusite, when fresh, is greenish or reddish and transparent. Usually, however, it is more or less altered, and is opaque, or perhaps translucent, and

gray, pink, or violet. The hardness of the fresh mineral is 7 and its sp.gr. 3.2.

Some specimens contain inclusions of a dark gray or black, possibly carbonaceous, material arranged in such a way as to form a dark cross, when the crystals are cut across and polished. This variety is called *chiastolite*. It was once valued as a sacred charm.

Before the blowpipe, andalusite is infusible. When moistened with cobalt nitrate and heated, it becomes blue (see p. 147). It is insoluble in acids.

Andalusite is distinguished by its hardness, infusibility, and the reaction for Al. It is distinguished from staurolite (No. 93) by the form of its crystals, which have a nearly square cross-section.

The only use of andalusite is as a semi-precious stone, and for this purpose only the chiastolite variety is of any value.

91. Topaz ($Al(Al(F,OH)_2)SiO_4$) is a common constituent of many ore veins, and is often present

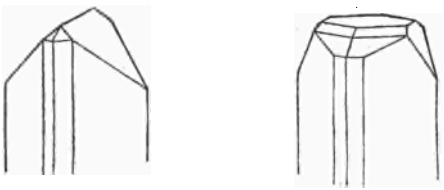


FIG. 58.—Topaz Crystals.

as crystals on the walls of cracks and cavities in volcanic rocks. It varies in composition, since it is apparently a mixture of $Al(AlF_2)SiO_4$ and $Al(Al(OH)_2)SiO_4$. It occurs massive and in prismatic orthorhombic crystals (Fig. 58), often contain-

ing a great number of planes. The cleavage is perfect perpendicular to the long axes of the crystals.

The mineral is colorless, honey-yellow, yellowish-red, rose and, rarely, bluish. When exposed to the sunlight, the colored varieties fade, and, when intensely heated, some honey-yellow crystals turn rose-red. The mineral is transparent and has a colorless streak. Its hardness is 8 and its sp.gr. 3.5.

Topaz is infusible before the blowpipe and insoluble in acids. At a high temperature, it loses its F and OH. It gives the ordinary reactions for these substances.

The mineral is easily recognized by its crystallization, its hardness, and its reaction for fluorine (p. 155). It is distinguished from yellow quartz by its easy cleavage and its greater hardness.

It is frequently found coated with a micaceous product which may be steatite, muscovite, or kaolin (Nos. 105, 96, 106).

Topaz occurs principally in coarse granites, especially those containing cassiterite (No. 40), in gneisses and in volcanic rocks.

It is used as a gem.

92. Epidote ($Ca_2(Al,Fe)_3(OH)(SiO_4)_3$) is a common alteration product of many other silicates. It usually occurs in slender prismatic crystals (Fig. 59), in granular aggregates and massive. Its crystals are striated longitudinally and have one perfect cleavage, which in most crystals is parallel to their long direction.

Ordinary epidote is yellowish-green, dark green, brown, and in some cases, red. It is transparent or translucent and has a glassy luster and a gray streak. Its hardness is 6.5 and its density 3.4.

Two varieties that have been given distinct names are:

Bucklandite, a greenish-black variety.

Withamite, a bright red variety, containing Mn.

Before the blowpipe, epidote yields water and fuses to a dark brown or black mass which is often magnetic. With increase in iron, fusion becomes easier. Before fusion, the mineral is insoluble in

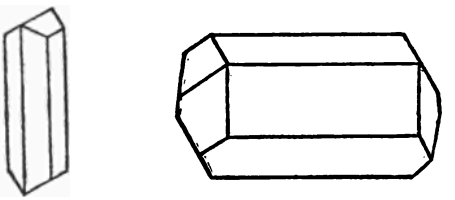


FIG. 59.—Epidote Crystals.

acid; but after heating, it decomposes in HCl with the separation of gelatinous silica.

The ordinary forms of the mineral are characterized by their yellowish-green color, easy fusibility and their crystallization. They are distinguished from malachite and olivine (Nos. 60, 85) by their insolubility in acids.

Epidote occurs in veins and as isolated crystals and druses on the walls of fissures and cavities in rocks.

It has no economic value. Its presence is an indication that the rock in which it occurs has been subjected to weathering or other alteration processes.

93. Staurolite ($Fe(Al \cdot OH)(AlO)_4(SiO_4)_2$) is interesting mainly because of its cross-shaped crystals and the fact that it is a characteristic product of metamorphic processes. It crystallizes in orthorhombic pris-

matic crystals that are often in twins, consisting of crossed crystals (Fig. 60).

The mineral is reddish or blackish-brown, with a greasy luster and a white streak. It is translucent in fresh specimens but opaque in weathered ones. It possesses one distinct cleavage. Its fracture is conchoidal; its hardness 7 and sp.gr. about 3.5.

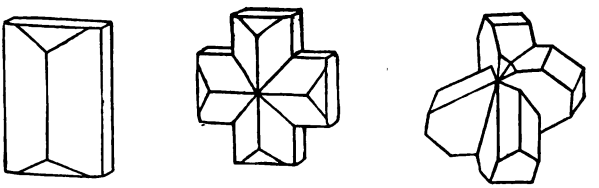


FIG. 60.—Staurolite Crystals.

Before the blowpipe, it is infusible, unless it contains some manganese, in which case it fuses to a black magnetic glass. It is only slightly attacked by H_2SO_4.

Staurolite is easily recognized by its crystallization, infusibility and hardness.

It occurs principally as crystals embedded in mica schists and other metamorphic rocks.

Its crystals are mounted and used as watch charms.

94. Nephelite ($(Na,K)AlSiO_4$) is important principally as a rock constituent. Its crystals are hexagonal prisms in habit (Fig. 61).

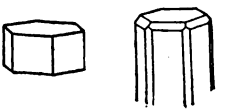


FIG. 61.—Nephelite Crystals.

The mineral is white or gray; transparent and glassy when fresh. When occurring as grains in old rocks, it may be pink, brown, yellowish or greenish; translucent, and greasy in luster. This form is often

designated *eleolite*. The streak is always white. Its hardness is 5–6 and sp.gr. 2.6.

Before the blowpipe, the mineral melts to a white or colorless, bubbly glass. Its powder before and after roasting reacts alkaline. It dissolves easily in HCl with the production of a voluminous precipitate of gelatinous silica.

Nephelite is distinguished by its crystals, its hardness and its gelatinization with acids; eleolite by its gelatinization and greasy luster.

It occurs in crystals implanted on the walls and cavities in volcanic rocks and as grains in them.

The Micas.—The micas are a group of minerals that are characterized by such a very perfect cleavage in a single direction that thin plates may be split from them with ease. Moreover, in the true micas these plates are elastic; that is, they may be bent without breaking, and when the bending force is removed they fly back to their original positions. Some of the micas are of great economic importance, but for others no use has yet been found. Chemically, the micas are very complex. They may be separated into:

(1) The *magnesium iron micas*, of which *biotite* is the best illustration.
(2) The *calcium micas*.
(3) The *lithium-iron micas*.
(4) The *alkaline micas*.

Of the latter there are three subdivisions:

(*a*) The *lithium micas*, represented by *lepidolite*.
(*b*) The *potash mica, muscovite*.
(*c*) The *soda mica, paragonite*.

95. Biotite ($(K,H)_2(Mg,Fe)_2(Al,Fe)_2(SiO_4)_3$) **is the** principal magnesian mica. Its composition is represented approximately by the formula given above. Those varieties in which Fe replaces nearly all the Mg are known as *lepidomelane*. Those in which Mg is in great excess are called *phlogopite*. Biotite includes the remaining.

The biotites occur in monoclinic crystals with an hexagonal habit, in flat scales, and scaly aggregates.

Their color varies from yellow, through green and brown to black, and they are strongly pleochroic. Their streak is white, luster glassy, hardness 2.5 and sp.gr. 2.7–3.1. They are transparent or translucent.

Before the blowpipe, the dark, ferruginous varieties whiten and fuse on thin edges to a black glass; the lighter colored ones, with greater difficulty, to a brown glass. In the closed tube, they yield a little water and some varieties give the reaction for fluorine (p. 155) in the open tube; phlogopite, nearly always. They are decomposed in strong H_2SO_4 with the separation of scales or flakes of SiO_2.

All the micas are easily distinguished from other minerals by their perfect cleavage into elastic foliæ, and the biotites from the other micas by their solubility in H_2SO_4. Lepidomelane is recognized by its black color, biotite by its dark greenish or dark brown color, and phlogopite by its amber color.

Biotite and lepidomelane occur as the constituents of igneous rocks and of certain mica schists. Phlogopite is especially characteristic of metamorphic limestones.

Phlogopite is used under the name of *amber*

mica in the manufacture of certain electrical appliances. The other biotites have no commercial value.

96. Muscovite ($H_2(K,Na)Al_3(SiO_4)_3$) is the alkali mica in which potassium predominates. It is one of the commonest of all the micas and at the same time the most valuable, because of its transparency. It occurs in tabular crystals that are orthorhombic or hexagonal in habit (Fig. 62), in broad plates, and in small flakes.

Muscovite is colorless or of some light shade of green, yellow or red. It has a glassy luster, a hardness of 2 and a sp.gr. of 2.76–3.1. It is pleochroic. It is a non-conductor of electricity at ordinary temperatures, and is a poor conductor of heat.

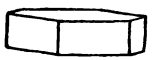


FIG. 62.
Muscovite Crystal.

Before the blowpipe, thin flakes of muscovite fuse on their edges to a gray mass. In the closed tube, the mineral yields water which, in some cases, reacts for F. It is insoluble in acids.

It is easily recognized as a true mica by its elastic cleavage foliæ and is distinguished from the biotites and ordinary lepidolite by its color. From colorless lepidolite and paragonite (Nos. 98, 97), it is distinguished by the flame test for K (p. 144).

The mineral occurs in large, ill-defined crystals, in coarse grains, as flakes in many igneous rocks, in some sandstones and slates and in mica schists. It also occurs in veins with other minerals.

It is employed in sheets for stove windows, gas-lamp chimneys, insulators in electrical apparatus, etc. Ground mica is used in wall paper, heavy lubricants and fancy paints. It is also mixed with shellac

and molded into shapes suitable for electrical insulators.

97. Paragonite ($H_2(Na,K)Al_3(SiO_4)_3$) is less common than muscovite. It apparently occurs most abundantly in certain fine-grained mica schists. It can be distinguished from muscovite only by chemical tests.

98. Lepidolite ($(Li,K,Na)_2((Al,Fe)OH,F)_2(SiO_3)_3$), the lithium alkali mica, occurs almost exclusively as aggregates of thin plates with hexagonal outlines; occasionally, in tabular crystals with centers of muscovite.

It is white, rose, light purple, gray or greenish, and transparent. Its streak is white, its luster glassy, its hardness 2 and sp.gr. 2.8–2.9.

It fuses easily to a white enamel and at the same time colors the flame crimson (Li). It is with difficulty attacked by acids, but after heating is easily decomposed.

Lepidolite is distinguished from the other micas by its color and its reactions for Li.

It occurs principally in coarse granite dikes and near the borders of granite masses. It is usually associated with rubellite and other bright-colored, transparent tourmalines (No. 108) and often with cassiterite (No. 40).

Lepidolite is utilized to a slight extent in the preparation of lithium salts, which are employed in medicine, photography and in the manufacture of fireworks and storage batteries.

99. Brittle micas differ from the true micas in that their cleavage foliæ are brittle. They are basic silicates of Ca, Mg, Fe and Al, one of the most common,

chloritoid, being approximately $H_2(Fe,Mg)Al_2SiO_7$. They usually occur in plates and scales that are alteration products of other minerals.

The brittle micas are green, red, brown or yellow, with a white streak, a hardness between 4 and 6 and a sp.gr. between 3.1 and 3.6. Most of them are transparent or translucent.

Before the blowpipe, they whiten on their edges and are infusible, or fusible with difficulty. All give off water when heated in the closed tube. Some are decomposed by HCl, but others are unattacked.

They are distinguished by their perfect cleavage and their brittleness.

They occur in metamorphosed limestone and in schists.

100. Chlorites are also micaceous, or scaly, decomposition products. They are hydrous silicates of Mg, Fe and Al in various proportions. The most common are *prochlorite* and *clinochlor*. The former contains about 15 per cent. MgO and the latter 35 per cent.

These two chlorites occur in small, tabular crystals in scaly aggregates and occasionally in earthy masses.

They are dark green in color, have a white or light-green streak, a glassy luster, and one very perfect cleavage. The hardness of prochlorite is between 1 and 2 and of clinochlor between 2 and 2.5 and their sp.gr. is between 2.6 and 2.9.

Before the blowpipe, they exfoliate and fuse on their edges. In the closed tube, all yield water when strongly heated. HCl attacks them with difficulty; H_2SO_4 with ease.

They are distinguished by their cleavage, color, softness, solubility in H_2SO_4 and manner of occurrence.

They are found as constituents of partially altered igneous rocks, and of schists. Chlorite schists are made up largely of chlorites and quartz (No. 34). The chlorites also fill veins, and form pseudomorphs after other minerals.

101. Leucite ($KAl(SiO_3)_2$), is an important rock constituent. It occurs almost exclusively in isometric crystals, resembling those of garnet (Fig. 63), or in small round grains.

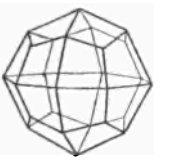


FIG. 63.—Leucite Crystal.

It is white or light gray, with a glassy luster, and a white streak. It is brittle and transparent or translucent, and has a hardness of 5–6 and a sp.gr. of 2.5. Because it easily decomposes, most specimens appear white and opaque.

Before the blowpipe, leucite is infusible, but colors the flame for K. It is soluble in HCl with the production of pulverulent silica. Its powder reacts alkaline.

Leucite is distinguished from most other minerals by its crystallization. It is distinguished from white garnet (No. 88) by its inferior hardness and from analcite (No. 130) by its infusibility and the fact that it contains no water. Moreover, analcite fails to give the flame reaction for K (p. 144).

The mineral occurs principally in igneous rocks, especially lavas that are rich in potash. It has no commercial value at the present time, but it has been suggested that it might be made a source of potash salts.

102. Kyanite, cyanite ($(AlO)_2SiO_3$) or **disthene** is an abundant component of some schistose rocks. The name, "kyanite", suggests the sky-blue color noticed in many specimens, and the name, "disthene", refers to the difference in hardness exhibited in different directions.

Kyanite is usually found in long, flat, isolated blades (Fig. 64) with a perfect longitudinal cleavage.

FIG. 64.—Kyanite Crystals in Quartzite.

Its luster is glassy, except on cleavage surfaces, where it is pearly.

The mineral is commonly light blue and transparent or translucent. Less commonly, it is colorless or white, yellow, green or gray. Its hardness on the cleavage plane is about 5 in the longitudinal direction and 7 perpendicular to this.

Before the blowpipe, kyanite is infusible. With cobalt solution, it reacts for Al (p. 147). It is insoluble in acids.

Kyanite is not easily confused with other minerals. It is distinguished from the few which it resembles by the great difference in hardness in different directions on its cleavage faces.

It occurs in micaceous schists and schistose quartzites.

The blue transparent variety is sometimes used as a gem.

103. Beryl ($Be_3Al_2(SiO_3)_6$), a frequent constituent of coarse-grained granites, occurs in well-defined

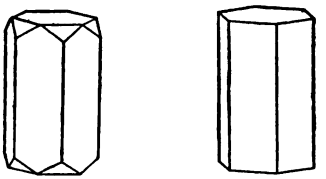


FIG. 65.—Beryl Crystals.

prismatic hexagonal crystals (Fig. 65), in some instances of great size, and in granular aggregates and massive.

It is colorless or light green, red or blue, and is transparent or translucent. Its streak is white, luster glassy, hardness 7 to 8 and sp.gr. about 2.7.

Before the blowpipe, colorless varieties become milky, but others are unchanged except at very high temperatures, when sharp edges are fused to a porous glass. The mineral is not attacked by acids.

It is distinguished from apatite (No. 72) by its greater hardness.

The mineral occurs as crystals or crystalline masses in coarse granites, in schists, in ore veins, in slates and rarely in limestone.

Its transparent varieties are used as gems under the following names:

Emerald, a deep green variety.
Aquamarine, a blue-green variety.
Golden beryl, a topaz-colored variety.
Blue beryl, a blue variety.

104. Serpentine ($H_4Mg_3Si_2O_9$) is a common alteration product of olivine (No. 85), pyroxenes (Nos. 110, 111), and a few other silicates. It occurs principally in fibers filling veins (*chrysotile*), as scales, and massive.

It is white, gray, brown, or green, with a white streak and a dull, slightly glistening or greasy luster. The variety known as *noble serpentine* is nearly transparent and has a clear greenish or yellowish-white, yellowish-green, apple-green, or dark green color. Other varieties are translucent or opaque. When pure, its hardness is 3 and its sp.gr. about 2.6.

Before the blowpipe, the mineral fuses on thin edges. It yields water in the closed tube, reacts for Mg (p. 147), and is decomposed by HCl and H_2SO_4 with the separation of gelatinous silica. Its powder reacts alkaline.

Serpentine is distinguished from steatite (No. 105) by its solubility in HCl and its greater hardness.

The fibrous, nearly transparent, white serpentine, known as *chrysotile*, is mined as asbestus. It is distinguished from amphibole asbestus (No. 115) by the test for water. Massive varieties are used as building stone, or are ground and used as a paper filler, etc. The finer varieties are sawed into slabs and these are employed for interior decoration. The various uses of asbestus are too well-known to need mention.

105. Talc or **steatite** ($H_2Mg_3(SiO_3)_4$) is usually found in flaky, foliated and massive forms, and at a few places in small acicular or prismatic crystals. It is an important economic product.

The mineral is white, gray, greenish or bluish and is transparent or translucent. Its streak is white. The massive forms, known as *soapstone*, are white, gray or some other light shade. All varieties are soft (H = 1) and all have a soapy feeling. The sp.gr. of the pure talc is 2.6–2.8.

Before the blowpipe, talc exfoliates, hardens and glows brightly, but it is nearly infusible, melting only on the thinnest edges to a white enamel. It yields water in the closed tube, only at a high temperature. It is unattacked by acids before and after heating.

It is distinguished from other white, soft minerals by its insolubility in acids, and the reaction for Mg (p. 147).

Talc occurs as large plates and groups of plates in metamorphosed limestone, as fibers in schists, as veins cutting serpentine (No. 104), as layers composed of talc and quartz (talc schist), associated with other schistose rocks, and as pseudomorphs after other minerals. Soapstone occurs in rock masses.

The white talc is ground and used as a lubricator, a toilet powder, a filler in cloth, paper, etc. Soapstone is sawed into slabs and employed in lining acid vats, laundry tubs, making electric switchboards, and for many other uses requiring a non-absorbent and infusible material.

106. Kaolinite ($H_4Al_2Si_2O_9$) is one of the principal ingredients of clay. As such, it is of great economic value. It occurs in tiny, thin tabular crystals and in scaly, foliated and earthy aggregates.

When pure, it is white or colorless and transparent. In masses it is earthy; in crystals, glassy. Its hardness is 1, and its sp.gr. 2.5.

Before the blowpipe, kaolinite is infusible. It is only slightly attacked by acids, but is decomposed by alkalies and alkaline carbonates with the separation of gelatinous silica. In the closed tube, it yields water when heated.

It is characterized by its softness, insolubility in acids and by the $Co(NO_3)_2$ test for Al (p. 147). It is distinguished from chalk (No. 50) by its reaction toward HCl, from infusorial earth (No. 42) by its softness, and from talc (No. 105) by the reactions for aluminium.

Kaolin is an earthy, friable mass of kaolinite which becomes plastic when moistened.

Clay is a mixture of kaolinite and other flaky and fibrous minerals. The greater the proportion of kaolinite in it the more plastic it is and, consequently, the more valuable.

Since kaolinite is a weathering product of other silicates, it occurs in little masses through rocks. It is found also in layers and pockets of nearly pure material.

Kaolin and clay are used in the manufacture of pottery, brick, tile, etc.

107. Calamine $(ZnOH)_2SiO_3$ is an ore of zinc. While theoretically a pure zinc compound, it usually contains also a little iron and frequently some lead. It occurs in small brilliant, tabular crystals (Fig. 66), implanted on the walls of zinc and lead ores. Often, many crystals are grouped in fibrous or warty aggregates and in crusts. It is found also in granular and compact masses.

The mineral is glassy, transparent or translucent and when pure is colorless or white. Usually, however, it is gray, yellow, brown, greenish or blue. Its streak is white, its hardness, 4–4.5, and its sp.gr. 3.4. It is brittle and strongly pyroelectric, and it becomes phosphorescent when rubbed.

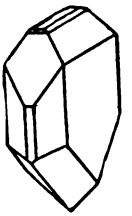


FIG. 66. Calamine Crystal.

Before the blowpipe, it is almost infusible, but on charcoal it swells and colors the flame greenish. When fused with Na_2CO_3, it gives the zinc sublimate (p. 147) which, when heated and moistened with $Co(NO_3)_2$ solution, changes to green. In the closed glass tube, it decrepitates, yields water and becomes cloudy. It dissolves in weak acids with the production of gelatinous silica.

Calamine is distinguished from smithsonite (No. 54) by its reaction for acids and from other minerals by its crystallization and the reaction for zinc (p. 147).

Calamine is found principally in veins with other zinc ores, with which it is mined.

108. Tourmaline ($R'_9Al_3(B\cdot OH)_2Si_4O_{19}$), in which R′ = H, Na, Li, Mg, Cr, Al, Fe, is a common mineral of very complex composition. It is more properly the name of a group of compounds that occur mixed in many proportions. The mineral occurs in handsome prismatic and acicular crystals, nearly all of which have a triangular cross-section (Fig. 67).

Their colors are varied, depending upon their composition. Those in which the alkalies predominate are colorless, red, blue or green and transparent. Those in which iron predominates are black and translucent. Magnesium varieties are yellowish-brown and

translucent and chromium varieties, dark green, black and translucent, or colorless and transparent.

The varieties designated by distinct names are:

Ordinary, black or brown.
Rubellite, pink or red.
Indicolite, blue or blue-black.
Brazilian sapphire, blue and transparent.
Brazilian emerald, green and transparent.
Peridot of Ceylon, honey-yellow and transparent.
Achroite, colorless and transparent.

Tourmaline, whatever its color, is brittle. Its luster is glassy, and its streak is white. It has no

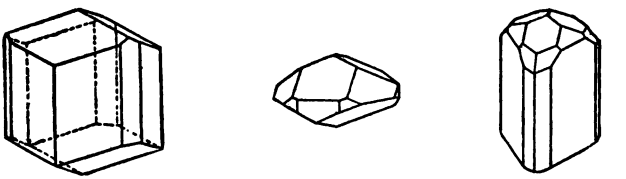


FIG. 67.—Tourmaline Crystals.

distinct cleavage. Its fracture is conchoidal. Its hardness is 7–7.5 and its sp.gr. 3–3.2. The color, in many instances, differs in different portions of the same crystal, the arrangement in some cases being concentric. The mineral is strongly pleochroic; i.e., it possesses different colors when looked through in different directions.

Its behavior before the blowpipe varies widely. Alkaline varieties are nearly infusible. Iron varieties fuse with difficulty and magnesium varieties easily to a bubbly glass. When fused with a mixture of $HKSO_4$ and powdered fluorspar, the mineral gives a distinct reaction for boron (p. 152).

When in crystals, tourmaline is easily recognized by its form. Massive brown varieties resemble closely vesuvianite and garnet (Nos. 109, 88). The boron test identifies it.

Tourmaline occurs in quartz and ore veins, in metamorphosed limestones, in schists and in granites and other coarse-grained rocks. The lithium varieties are usually associated with the pink mica, lepidolite (No. 98).

The transparent tourmalines are used as gems; the dark translucent varieties in the manufacture of optical instruments.

109. Vesuvianite is a complex mixture of basic calcium-aluminium silicates often containing some fluorine. It occurs both massive and crystallized.

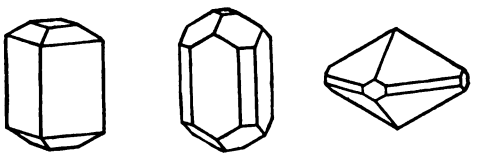


FIG. 68.—Vesuvianite Crystals.

Its crystals are columnar (Fig. 68), pyramidal or acicular, usually with a square or octagonal cross-section. They possess no distinct cleavage.

Vesuvianite is glassy in luster and yellowish, greenish or brownish in color. It is transparent or translucent and its streak is colorless. A rare green or gray and green translucent massive variety is known as *californite*. Its hardness is 6–7 and sp.gr. 3.3–3.5.

Before the blowpipe, vesuvianite melts to a brown or green glass. It is decomposed with difficulty by

acids, but after being heated it dissolves slowly with the separation of gelatinous silica.

Vesuvianite is identified when in crystals by its form. Massive varieties are apt to be confused with garnet, tourmaline and epidote (Nos. 88, 108, 92). They are distinguished from the latter by their much easier fusibility.

The mineral is found as crystals on the walls of veins, where it is associated with quartz, calcite, garnet and ore minerals, and as grains in metamorphosed limestones and in crystalline schists.

Californite and a blue variety, containing copper and known as *cyprine*, are used as gems.

PYROXENES AND AMPHIBOLES

The pyroxenes and amphiboles comprise a large group of complex silicates that crystallize in various systems with different habits. The amphiboles are distinguished by having a prismatic cleavage intersecting at angles of 56° and 124° and the pyroxenes by possessing a similar cleavage intersecting at about 87° and 93°. They are all silicates of Mg, Ca or Fe, with alkalies, Mn and Al, in certain cases.

The pyroxenes are widely spread as the constituents of igneous rocks and of veins that have been filled by igneous processes. Their crystals are usually prismatic, with a distinct cleavage parallel to two of the prismatic planes. Their cross-sections are represented in Fig. 69*a*. The best-known pyroxenes are *bronzite, augite* and *spodumene*.

110. Bronzite ($(Mg,Fe)SiO_3$) is a mixture of $MgSiO_3$, which is known as *enstatite*, and $FeSiO_3$, known as

hypersthene. The three minerals are found as crystals, fibrous and lamellar masses and plates.

The color of bronzite varies with the proportion of Mg and Fe present. Enstatite is light gray, yellow or green; bronzite, brown, purple or green; and hypersthene, black, dark purple or dark green. All varieties have a colorless streak, and many show a metallic shimmer on certain planes. The hardness of enstatite is 5.5 and its sp.gr. 3.2. The corresponding properties of hypersthene are: H = 5–6; sp.gr. = 3.45.

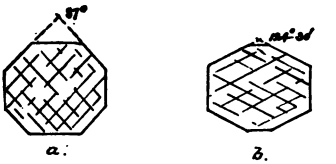


FIG. 69.—Cross-sections of Pyroxenes (*a*) and Amphiboles (*b*).

Before the blowpipe, the iron-free members are infusible. With increase in iron, the ease of fusibility increases, nearly pure hypersthene fusing to a greenish-black, weakly magnetic glass. When treated with HCl, the members near enstatite are unattacked and those near hypersthene are slightly decomposed.

When in crystals, bronzite is easily recognized by its forms and cleavage. Massive and fibrous varieties must be recognized by their general appearance and their manner of occurrence.

They weather to serpentine, talc (Nos. 104, 105), and amphibole.

These pyroxenes are found in igneous rocks and in veins.

111. Augite is a Mg-Fe-Ca pyroxene containing Al. It may be represented as a mixture of $(Mg,Fe)Ca(SiO_3)_2$ and $(Mg,Fe)(Al,Fe)_2SiO_6$. It occurs as crystals and grains in igneous rocks, in schists, and in veins with ore minerals, especially magnetite (No. 47).

Its crystals are short, prismatic (Fig. 70), and have the usual prismatic cleavage. They are all glassy in luster and their color varies with their composition, greenish and purplish-black tints predominating.

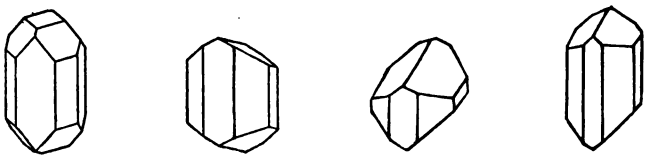


FIG. 70.—Augite Crystals.

Their streak is white; hardness 5–6 and sp.gr. about 3.5.

Before the blowpipe, augite is fusible, the ease of fusibility increasing with the amount of iron present. It is insoluble in acids.

Augite is distinguished from other silicates by its crystallization and cleavage.

The principal varieties are:

Fassaite, pale to dark green.

Augite, dark green or brownish-black. Sp.gr. 3.24.

Diallage, characterized by a distinct parting in addition to the usual prismatic cleavage, and a lamellar structure.

Under the influence of surface agencies, augite alters to hornblende (No. 116), the corresponding amphibole,

and to serpentine (No. 104), to chlorites (No. 100), and other hydrous compounds.

112. Spodumene ($(Li, Na)Al(SiO_3)_2$) is an alkaline pyroxene which is used to some extent as a source of lithium compounds. It occurs as large columnar or tabular crystals (Fig. 71) which are striated vertically, and as platy or scaly aggregates. Its cleavage is perfect, as in the other pyroxenes.

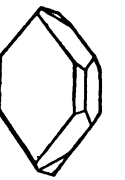


FIG. 71. Spodumene Crystal.

The mineral has a glassy luster, approaching pearly on cleavage surfaces. It is white, greenish, or amethystine in color and its streak is white. It is transparent or translucent, has a hardness between 6 and 7 and a density of 3.2.

Before the blowpipe, it swells and fuses to a colorless glass, at the same time imparting a crimson tinge to the flame. It is unattacked by acids. Its powder reacts alkaline.

It is characterized by its cleavage, and the color it imparts to the flame. It has a higher sp.gr. than feldspar (Nos. 118–120) and is less fusible than *amblygonite*—a lithium phosphate.

Spodumene occurs as crystals and grains in granites and crystalline schists.

The ordinary varieties are used in manufacturing lithium salts and the transparent varieties as gems. Of the latter, *hiddenite* is emerald-green and glassy; and *kunzite*, pink or lilac.

The amphiboles, like the pyroxenes, occur in igneous and sedimentary rocks and as the fillings of veins. They occur also as frequent components of schists and other metamorphic rocks. The most common

members of the group are *tremolite, actinolite, hornblende* and *glaucophane.* All the amphiboles are found in crystals (Fig. 72), some of which have the same habit as pyroxene crystals; most of them, however, are more acicular. Their cross-sections are illustrated in Fig. 69*b*.

113. Tremolite ($Mg_3Ca(SiO_3)_4$), though occasionally in crystals, is more frequently found in long needles or plates.

The mineral is white or light green and transpar-

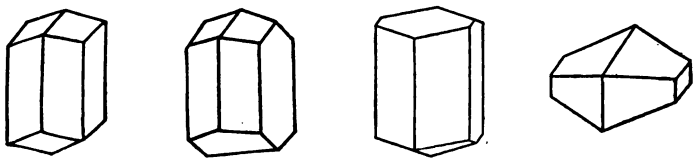


FIG. 72.—Amphibole Crystals.

ent or translucent. Its luster is glassy; its streak white; its hardness about 5.5, and its sp.gr. about 3.

Before the blowpipe, tremolite fuses only on thin edges. It is unattacked by acids. Its powder, especially after roasting, reacts alkaline. It gives a pink reaction for Mg with $Co(NO_3)_2$ solution.

Tremolite is characterized by its acicular crystals, color, cleavage and the reaction for Mg.

It occurs principally in metamorphosed limestones.

114. Actinolite differs from tremolite in containing a notable quantity of ferrous iron. It is light or dark green and has a very light streak. Its sp.gr. is 3.1. It is usually in thin, needle-like crystals or in fibrous or granular aggregates.

When heated before the blowpipe or on charcoal, it fuses with difficulty to a magnetic bead.

Actinolite is especially common in schists. In some, it occurs in such large quantiy as to constitute their principal component. Actinolite schists are rocks composed essentially of actinolite and quartz.

115. Asbestus is a fibrous variety of tremolite or actinolite. It occurs principally in limestones and a few other rocks which have been crushed and sheared. It has the same uses as chrysotile asbestus (No. 104), but is not regarded with as much favor because less pliable.

116. Hornblende occupies the same position among the amphiboles as does augite among the pyroxenes. It is the aluminous amphibole composed of a mixture of $(Mg,Fe)_3Ca(SiO_3)_4$ and $(Mg,Fe)((Al,Fe)O)_2SiO_4$.

It occurs usually in short, prismatic crystals (see Fig. 72) with the habit of those of augite, in long acicular or platy crystals and in granular masses. It possesses the distinct amphibole cleavage of 56° and 124°, by which it is distinguished best from augite.

Hornblende is black or dark green, with a glassy luster, a white streak, a hardness of 5.5 and a sp.gr. of 3–3.5, depending upon the proportion of the iron molecule present.

Before the blowpipe, it fuses with difficulty on thin edges. Heated on charcoal, it gives a magnetic globule. It is unattacked by acids.

It is best recognized by its crystallization and cleavage.

Several varieties are designated by distinct names:

Common hornblende is greenish-black.

Edenite is white, gray or light green. It contains very little iron.

Basaltic hornblende is black. It contains much ferric iron.

Hornblende occurs in igneous and metamorphic rocks and also as a constituent of veins. In some schists—the amphibolites—it is the predominant component. In others—the hornblende schists—it is associated with quartz.

117. Glaucophane differs in appearance from ordinary hornblende in that it is blue, purple, or bluish-black. It is essentially a mixture of $NaAl(SiO)_3$ and $(Fe,Mg)SiO_3$. It rarely occurs in crystals, but usually is in grains and plates in schistose rocks.

Glaucophane is translucent and strongly pleochroic. Its streak is gray-blue, it hardness about 6 and its sp.gr. about 3.

Before the blowpipe, it turns brown and then melts to an olive-green glass, coloring the flame for sodium. It is with difficulty attacked by acids.

Glaucophane is distinguished from other amphiboles by its color, and from other blue silicates by its hardness and manner of occurrence.

It is an essential constituent of glaucophane schists and an accessory component in other metamorphic rocks.

FELDSPARS

This group consists of minerals that are essentially alumino-silicates of the alkalies and calcium, rarely also of barium. There are two sub-groups distinguished by their methods of crystallization. In one, the two cleavages, which are present in all feldspars, are perpendicular to one another. The group is apparently monoclinic. In the other group, the cleavages are inclined at an angle that departs slightly from 90°. This group is triclinic.

All the feldspars are light-colored when pure, and translucent or transparent, and all have a white streak. Nearly all are insoluble in acids and, with difficulty, fusible before the blowpipe. They possess two distinct cleavages that yield fairly smooth, glistening surfaces. Their hardness is 6 and their sp.gr. varies between 2.55 and 3.34.

The feldspars are easily distinguished from nearly all other silicates by their color, hardness and easy cleavage into platy fragments with glistening surfaces.

Feldspars occur in veins, in ore bodies and as components of many igneous and metamorphic rocks. *Pegmatite* is a coarse-grained rock occurring in veins, and consisting of feldspar, quartz and usually mica or hornblende.

Though abundant, the feldspars have comparatively few uses. In the future, the potash varieties may become sources of the potash salts used in fertilizers, but at present their principal uses are in the manufacture of porcelain, and other white pottery products and of enamel ware. They are used also as fluxes and are employed in making opalescent glass, scouring soaps, window washes and ready roofing.

118. Orthoclase ($KAlSi_3O_8$) is the principal monoclinic feldspar. It is one of the two potassium feldspars; the other, *microcline*, being triclinic. It occurs in crystals and in crystalline grains.

The crystals are simple and twinned. Simple crystals are all more or less prismatic (Fig. 73). Their habits are equidimensional, columnar or tabular. Twinned crystals are of several kinds. Carlsbad twins consist of two crystals intergrown, as in Fig. 74 *a*. Baveno twins are columnar groups of parts of

two crystals grown together along a plane parallel to the columnar axis, as in Fig. 74 *b*. The result of this twinning is a square prism, with its ends crossed by a diagonal that separates the two individuals.

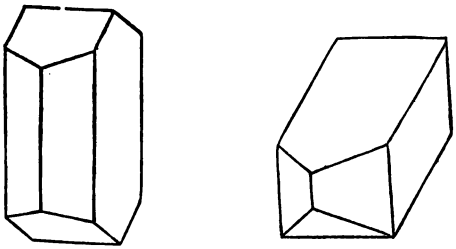
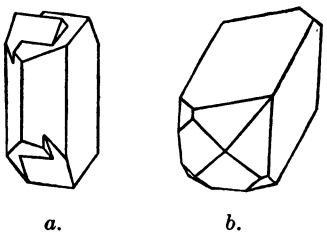


FIG. 73.—Simple Crystals of Orthoclase.

Orthoclase may be colorless or light-colored, transparent or translucent. Its cleavage is perfect, or nearly so, in two perpendicular directions. Its sp.gr. is 2.55.

Before the blowpipe, fragments of orthoclase are with difficulty fusible on their edges to a porous



a. *b.*

FIG. 74.—Twinned Crystals of Orthoclase.

glass, at the same time coloring the flame violet (K). The mineral is insoluble in HCl.

Orthoclase alters readily to kaolin and quartz and to muscovite (Nos. 106, 34, 96).

Several varieties are designated by distinctive names:

Adularia is a transparent variety, occurring in veins. Its crystals are of a different habit from those of other orthoclases.

Moonstone is a translucent adularia, exhibiting a pearly luster.

Sanidine is a glassy orthoclase containing some soda, which occurs in large, flat crystals in certain lavas.

Sunstone is a translucent variety, exhibiting reddish flashes from inclusions of mica or other platy minerals.

Perthite is a group of parallel intergrowths of thin lamellæ of orthoclase and albite (Nos. 118 and 120).

The principal use of orthoclase is in the pottery industry.

119. Microcline ($KAlSi_3O_8$) differs from orthoclase mainly in its crystallization. It is triclinic and nearly

FIG. 75.—Thin Section of Microcline as Seen between Crossed Nicols. (After Iddings.)

always twinned in such a way that thin sections, when viewed in polarized light between crossed nicols, exhibit series of light and dark bars crossing one another perpendicularly (Fig. 75). This grating structure is not visible to the unaided eye.

The ordinary physical and chemical properties of microcline are the same as those of orthoclase and, consequently, the two minerals can be distinguished only by crystallographic or optical means.

Microcline is a common constituent of certain igneous rocks and crystalline schists and of some pegmatites.

120. Plagioclase.—This name is given to the series of soda-calcium feldspars, all of which are triclinic. Their cleavages are inclined to one another at angles that depart slightly from 90°. Nearly all the plagioclases contain small quantities of potassium. The members of the series with their compositions and sp.gr. are as follows:

Albite	$NaAlSi_3O_8$(Ab)	SiO_2 = 68.7%	Sp.gr. = 2.605
Oligoclase	Ab_6An – Ab_3An	SiO_2 = 62.0%	Sp.gr. = 2.649
Andesine	Ab_3An – AbAn	SiO_2 = 55.6%	Sp.gr. = 2.679
Labradorite	AbAn – $AbAn_3$	SiO_2 = 49.3%	Sp.gr. = 2.708
Bytownite	$AbAn_3$ – $AbAn_6$	SiO_2 = 46.6%	Sp.gr. = 2.742
Anorthite	$CaAl_2(SiO_4)_2$(An)	SiO_2 = 43.2%	Sp.gr. = 2.765

Albite, the pure or nearly pure, soda plagioclase, contains 68.7% SiO_2 and anorthite, the calcium plagioclase, contains 43.2% SiO_2. Thus, albite contains more of the acid radical than does anorthite and is, therefore, said to be more acid. On the other hand, anorthite is said to be more basic. The other members of the group are mixtures of these two in the proportions designated in the table (thus, andesine includes those plagioclases containing between one and three parts of albite to one of anorthite). Their relative acidity is indicated by their position in the table with respect to albite and anorthite, or by the proportion of the albite molecule in the mixture. The percentages of

SiO_2 given correspond to those mixtures opposite each name containing the smallest proportion of albite. Thus, andesine is more acid than labradorite and it contains from 55.6% to 62% of SiO_2.

Crystals of the plagioclases are like those of orthoclase. The soda-rich members usually contain many planes. The lime-rich members are simpler. Twins, like those of orthoclase, are not uncommon, but much more common are the albite and pericline twins, which are of a different type. Albite twins are made up

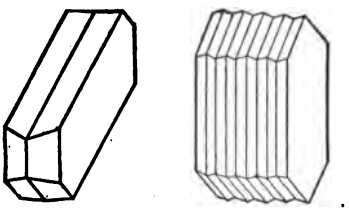


FIG. 76.—Albite Twins of Plagioclase.

of two or many parallel plates that are arranged perpendicularly to the most perfect cleavage (see Fig. 76). Therefore, the most perfect cleavages across plagioclases twinned according to this plan exhibit parallel striations when examined in light reflected at the proper angles (Fig. 77). In the pericline twins, there are also alternations of lamellæ, but their positions are such that they are perpendicular, or nearly so, to the positions of the albite lamellæ. Frequently, both methods of twinning are observed in the same specimen; in which case, the two sets of striations can be seen crossing each other at angles of 90° or thereabout (Fig. 78). Microcline, though not a plagioclase, exhibits this double-twinning clearly (compare Fig. 75).

The plagioclases resemble very closely orthoclase and microcline in their general character, though pinkish and greenish shades are rare. Their densities

Fig. 77.—Twinning Striations on Cleavage Surface of Oligoclase. Natural Size.

vary with their composition, as indicated in the table. They are usually translucent, but in some cases are transparent. Albite often exhibits a pearly luster and often a bluish shimmer. Oligoclase affords the handsomest sunstones. The most brilliantly colored plagioclases are some forms of labradorite, which on cleavage surfaces show a great display of yellow, green, red, purple, and blue flashes in reflected light. The colors are supposed to be due to the presence of numerous, tiny, parallel, acicular inclusions, which act upon the light in the same way as the lines in a diffraction grating.

Fig. 78. Crossed Twinning Striations on Plagioclase Crystal.

Before the blowpipe, all plagioclases fuse to a white or colorless glass, at the same time coloring the flame yellow (albite) or yellowish-red (anorthite). Albite is

unattacked by HCl, but anorthite is decomposed by this reagent with the separation of gelatinous or pulverulent silica. The intermediate members of the series are more or less easily decomposed, as they contain more or less of the anorthite molecule.

The plagioclases are best distinguished from orthoclase and microcline by the colors imparted to the blowpipe flame and by the twinning striations on their cleavage surfaces. The best means of distinguishing the plagioclases from one another are their specific gravities.

The plagioclases weather to kaolin (No. 106) and mica (Nos. 96, 97) mixed with quartz and calcite (Nos. 34, 50). In rock masses, they often change to a dark gray mixture of epidote, garnet and other silicates known as *saussurite*.

Albite occurs in vein masses, in metamorphic rocks and rarely in igneous rocks. Oligoclase and andesine occur in granite and other siliceous igneous rocks and labradorite, bytownite and anorthite in the more basic rocks like basalt and gabbro (p. 197). Anorthite is also found in meteorites.

Albite is mined from pegmatite veins for use in the manufacture of pottery. A few of the other plagioclases are employed as gem stones.

Hydrated Silicates

121. Chrysocolla ($H_2CuSiO_4 \cdot H_2O$), an acid hydrate of copper, is an important ore in some places. It occurs either massive or in globular groups of fibers.

It is commonly a greenish-blue, translucent, opal-like or earthy mass with a greenish-white streak. Impure varieties may be brown or black, with a dark

brown or dark green streak. It has a conchoidal fracture and is brittle. Its hardness varies between 2 and 4 and its sp.gr. between 2 and 2.2.

The mineral is infusible before the blowpipe, but colors the flame green. It blackens and yields water in the closed tube, and is decomposed by HCl with the production of pulverulent silica. The solution reacts for Cu.

It is distinguished from other green and blue silicates except malachite (No. 60) by the green color it imparts to the flame. From turquoise (No. 78) it is distinguished by inferior hardness and the absence of phosphorus.

Chrysocolla is found in veins with other copper minerals, and as crusts coating volcanic rocks.

It is mined with other copper compounds as an ore of copper.

122. Apophyllite ($H_7KCa_4(SiO_3)_8 \cdot 4\frac{1}{2}H_2O$) is found

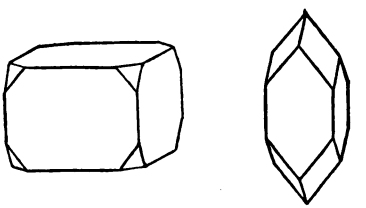


FIG. 79.—Apophyllite Crystals.

in brilliant prismatic crystals (Fig. 79), with a square cross-section and in granular and lamellar masses.

Its crystals have one very perfect cleavage, and the cleavage surfaces exhibit a distinct pearly luster. On other surfaces, the luster is glassy. Its color is white, gray or reddish and the streak colorless. Its hardness is 4.5–5 and sp.gr. 2.3.

Before the blowpipe, apophyllite exfoliates and fuses easily to a white, blebby enamel and imparts a violet color to the flame. In the closed tube, it yields some water at a low temperature and becomes opaque. The last traces of water are lost only at a red heat. Most specimens react for F. The mineral dissolves in HCl, yielding slimy silica.

Apophyllite is recognized by its crystals, its pearly luster on cleavage surfaces and in most instances by the reaction for F.

ZEOLITES

The zeolites comprise a group of minerals that are hydrous silicates of Al and of Ca, Sr, Ba, Na and K. The calcium and sodium compounds are the most common.

Some of them are primary minerals which resulted from the cooling of an igneous magma, but in the great majority of cases they are secondary products that have resulted from the alteration and hydration of alkali-aluminium silicates, such as the feldspars, leucite, nephelite, etc.

They are nearly always found in veins or on the walls of crevices in rocks (especially lavas), where they have been deposited by circulating water.

All are well crystallized, forming handsome crystals which in some cases are extremely complicated. They are transparent or translucent, and are usually of some light shade of color. Their luster is usually glassy and their streak is colorless.

Before the blowpipe, all the zeolites fuse with intumescence or bubbling, and all give water in the closed tube. They are comparatively soft (3.5–5.5) and have a low sp.gr.

The most common are the following with their compositions, hardnesses and specific gravities:

Phillipsite	$K_2CaAl_2(SiO_3)_4 \cdot 4\frac{1}{2}H_2O$	H., 4	Sp.gr., 2.2
Harmotome	$H_2(Ba,K_2)Al_2(SiO_3)_5 \cdot 5H_2O$	H., 4.5	Sp.gr., 2.5
Stilbite	$(Na_2,Ca)Al_2Si_6O_{16} \cdot 6H_2O$	H., 3–4	Sp.gr., 2.2
Laumontite	$H_4CaAl_2Si_4O_{14} \cdot 2H_2O$	H., 3–3.5	Sp.gr., 2.35
Scolecite	$Ca(AlOH)_2(SiO_3)_2 \cdot 2H_2O$	H., 5–5.5	Sp.gr., 2.3
Chabazite	$(Ca,Na_2)Al_2(SiO_3)_4 \cdot 6H_2O$	H., 4.5	Sp.gr., 2.1–2.16
Analcite	$NaAl(SiO_3)_2 \cdot H_2O$	H., 5–5.5	Sp.gr., 2.2–2.3
Natrolite,	$Na_2Al_2Si_3O_{10} \cdot 2H_2O$	H., 5–5.5	Sp.gr., 2.2–2.5

123. Phillipsite and (**124.**) **Harmotome** are distinguished by their complicated twinning when in crystals (Fig. 80). They are, however, sometimes

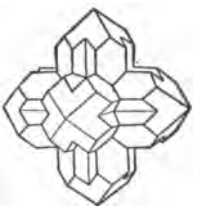


FIG. 80.—Harmotome Crystal.

FIG. 81.—Sheaf-like Group of Stilbite Crystals.

found in radially fibrous, globular aggregates. Crystals of harmotome have one distinct cleavage and those of phillipsite, two. They fuse to a white glass and are decomposed by HCl. Phillipsite and harmotome are distinguished by the fact that the solution of the former does not yield a precipitate with H_2SO_4, while that of the latter yields a white precipitate of $BaSO_4$.

125. Stilbite occurs in sheaf-like aggregates of tabular crystals (Fig. 81), in radiating bundles and in

thin, platy prisms. It has one perfect cleavage. Before the blowpipe it exfoliates, swells and crinkles. It is decomposed by HCl.

126. Laumontite occurs in prismatic crystals (Fig. 82) and in radial fibers. The crystals have two perfect cleavages. The luster on these surfaces is pearly. Before the blowpipe the mineral swells and melts to a white glass. It gelatinizes in HCl and readily yields some water at low temperatures. A red heat, however, is required to drive off the last traces.

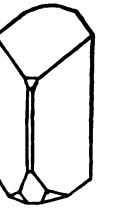


FIG. 82. Laumontite Crystal.

127. Scolecite is in silky, fibrous and dense, radiating masses, and also in acicular and columnar crystals which are often aggregated into divergent groups (Fig. 83). It has one perfect cleavage. Before the blowpipe, it crinkles and

FIG. 83.—Group of Scolecite Crystals.

fuses to a white enamel. In the closed tube, it becomes opaque. It gelatinizes with acids.

128. Chabazite occurs in rhombohedral crystals which have a cubical habit (Fig. 84). It occurs also in granular aggregates. It has a distinct cleavage,

parallel to the rhombohedral faces. Before the blowpipe, chabazite swells and fuses to a porous, translucent glass. In the closed tube, it loses water and cracks, but remains clear. It is decomposed by HCl, yielding slimy silica; but after fusion, it is insoluble. It is distinguished by its crystallization and its reaction in the closed tube.

129. Natrolite occurs in acicular crystals (Fig. 85) which are often arranged in radial and fibrous

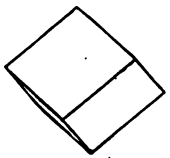


FIG. 84.—Chabazite Crystals.

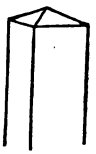


FIG. 85.—Natrolite Crystal.

aggregates forming tufts, and in granular and dense masses. It is usually glassy and possesses one distinct cleavage. Before the blowpipe, it fuses quietly to a colorless glass, coloring the flame yellow.

130. Analcite is found in isometric crystals (Fig. 86) like those of leucite and garnet (Nos. 101, 88).

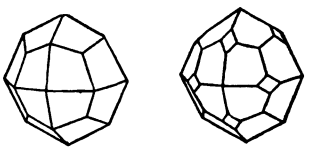


FIG. 86.—Analcite Crystals.

It possesses a very imperfect cleavage. Before the blowpipe, the mineral fuses to a colorless glass, imparting a yellow color (Na) to the flame. In the closed tube, it gives water, but retains its form and luster.

Its powder gelatinizes with HCl. It is distinguished from garnet (No. 88) by its much inferior hardness and its solubility in acid and from leucite (No. 101) by the presence of water, its easy fusibility, its inferior hardness, and the color it imparts to the flame. Besides occurring like other zeolites, analcite also occurs as an essential component of some lavas.

TITANATES AND TITANO-SILICATES

Titanates are salts of titanium acids analogous to those of silicic acid. Normal titanic acid is H_4TiO_4. The meta acid is $H_4TiO_4 - H_2O = H_2TiO_3$. Dititanates are salts of $H_2Ti_2O_5$ ($2H_4TiO_4 - 3H_2O = H_2Ti_2O_5$).

131. Titanite or **sphene** ($CaSiTiO_5$) may be regarded as a dititanate in which one Ti is replaced by

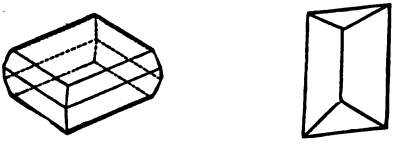


FIG. 87.—Titanite Crystals.

one Si. It occurs in crystals of various habits, some of which are double wedge-shaped (Fig. 87); others envelope-shaped; some prismatic, and others tabular. They have a prismatic cleavage.

The mineral is usually brown, gray, black or white. Its streak is white, and its luster vitreous. It is translucent or opaque. Its hardness is 5–5.5 and sp.gr. 3.5.

Before the blowpipe, sphene fuses to a dark glass. With beads, some specimens exhibit the reactions for manganese (p. 159) and all show those characteristic

of titanium. All varieties are sufficiently soluble in HCl to give the violet-colored solution when treated with tin. The mineral is completely decomposed by H_2SO_4. Sphene is distinguished from staurolite (No. 93) and garnet (No. 88) by its crystallization and softness; from sphalerite (No. 10) by its greater hardness and from other similarly colored minerals by the reactions for Ti (p. 164).

The mineral is a widespread constituent of igneous rocks, of many schists and of metamorphosed limestones. It occurs also as crystals on the walls of cracks and cavities in acid granular rocks.

132. Ilmenite ($FeTiO_3$), the iron metatitanate, looks very much like hematite (No. 38) when in crystals (Fig. 88) and very much like magnetite (No. 47) when massive. The mineral is rarely found in crystals. It is usually in homogeneous masses, in granular aggregates, in thin plates and in sand grains.

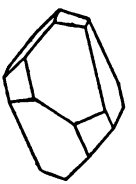


FIG. 88.
Ilmenite Crystal.

It is black and opaque and its streak is black or brownish-red. It has a submetallic luster, a hardness of 5–6 and a sp.gr. of 4.5–5. It is slightly magnetic.

Before the blowpipe, it is nearly infusible. It gives the reactions for iron (p. 141) with the beads. When the microcosmic salt bead, which is brownish-red in the reducing flame, is heated with a scrap of tin on charcoal, it changes to a violet-red color. The powder of ilmenite is slowly dissolved by hot HCl to a yellow solution, which, if filtered and boiled with the addition of tin, changes to blue, indicating titanium.

Ilmenite is distinguished from hematite by its streak, from magnetite by its lack of strong magnetism, and from almost all other heavy black minerals by its reaction for titanium (p. 164).

It is found as a constituent of many basic igneous rocks, as veins cutting them, and also as great masses near their contacts with other rocks. In a few places, it forms the principal component of sand.

Attempts have been made to utilize ilmenite as an ore of iron, but on account of its large content of titanium, no satisfactory means of smelting it on a commercial scale has been successful. At present, therefore, it has little value.

III

DETERMINATION OF MINERALS WITH THE AID OF THE BLOWPIPE

THE recognition of a mineral by mere inspection is often difficult, and is frequently impossible if crystals are not available. In this case, recourse is had to means that will aid in determining its chemical composition, or at least the nature of one or more of its constituents. The most convenient methods made use of for this purpose are those based on delicate and characteristic reactions that take place with solid reagents at high temperatures. The results are only qualitative, but when combined with the study of the physical properties of the substance tested they are sufficiently definite to enable one to recognize its nature. In a few instances, liquid reagents must be employed to give decisive results, but they are few and easily obtained. Analysis at high temperatures is known as blowpipe analysis, because the required heat is obtained by the use of the blowpipe.

The Blowpipe.—The blowpipe, in its simplest form, is a tube with a small outlet through which a current of air may be directed through a flame upon a small particle of substance. A practical instrument consists of a mouthpiece, a tube, an air-chamber to catch moisture, a side tube and a tip pierced by a tiny hole (Fig. 89). The tip is placed in the flame of a Bunsen

burner, an alcohol lamp or some other source of flame, and a current of air is blown through it by placing the mouthpiece to the lips, breathing full, and allowing the contraction of the cheeks to force the air from the mouth. Other forms of blowpipe are advocated for special purposes. Frequently, the side tube is curved in such a way that the air passing through is heated before it issues from the tip and a hotter flame is produced than is possible with the simpler instrument.

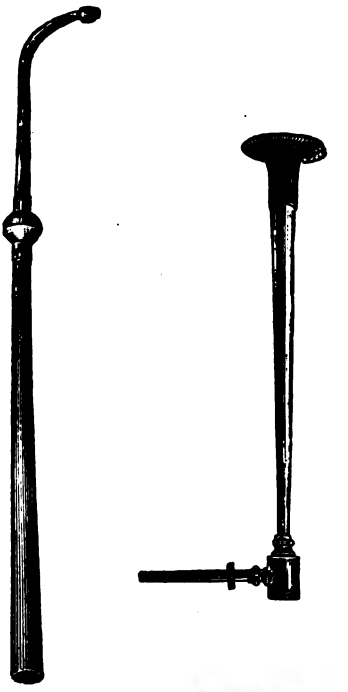


Fig. 89.—Simple Blowpipe.

Since it is often desirable to have both hands free to manipulate the assay, a blower is sometimes attached to the blowpipe.

Source of Heat.—The best source of flame for general use with the blowpipe is the Bunsen burner supplied by ordinary gas, and furnished with a tip which is flattened at the upper end and cut off obliquely. The blowpipe is supported on the upper end of this tip and pointed downward parallel with it. Thus, the flame is blown down upon the assay.

Since, however, illuminating gas often contains

noticeable traces of sulphur, for the detection of this substance it is often advisable to substitute an alcohol lamp for the gas burner. With the alcohol should be mixed a little turpentine in the proportion of one part of the latter to twelve of the former to increase the reducing power of the flame.

Supports.—The principal supports used to hold the material under investigation—the assay—are charcoal, platinum, and glass. Sheets of aluminium, plaster slabs and unglazed porcelain are also sometimes employed, but for most purposes the first three are entirely adequate.

Charcoal.—Charcoal is used in reduction tests and in the study of sublimates. It should have a flat surface and should be well burned.

Platinum.—Platinum is used principally in the form of wire and foil. The wire should be of about the thickness of coarse horsehair (.4 mm.), and should be fused into a 3-inch long glass tube to serve as a handle. It is employed mainly in the production of colored glasses or beads. The foil should be thin. When about to be used, it should be bent into a shallow cup in which mixtures may be fused.

Glass.—Glass is used in the form of tubes. These should be of a hard glass about 90 mm. long and 6 mm. inside diameter. When closed at one end, they serve to hold substances which are to be heated to a high temperature in the study of their volatile constituents. Tubes open at both ends are employed to study the effect of roasting the assay in a current of air.

Other Apparatus.—Other pieces of apparatus desirable for satisfactory blowpipe work are: a magnet, a magnifier, a pair of forceps, a small hammer, an anvil,

a pair of cutting pincers, a piece of blue glass or a screen composed of strips of celluloid colored different shades of blue, or a hollow glass prism filled with indigo solution.

Reagents.—Since blowpipe tests are made on minute quantities of material, it is necessary that all reagents used be as pure as possible. Those most frequently employed are: *borax*, $Na_2B_4O_7 \cdot 10H_2O$; *microcosmic salt*, or *salt of phosphorus*, $NH_4NaHPO_4 \cdot 4H_2O$; *fused sodium carbonate*, Na_2CO_3; *acid potassium sulphate*, $HKSO_4$; *niter*, KNO_3; *cobalt nitrate*, $Co(NO_3)_2 \cdot 6H_2O$, in solution; *copper oxide*, CuO; *magnesium ribbon*, Mg; *granulated zinc*, Zn; *sulphuric acid*, H_2SO_4; *hydrochloric acid*, HCl, and *blue litmus* and *turmeric papers*. Other reagents are employed in special tests, but those mentioned above are used generally.

The Blowpipe Flame.—The blowpipe flame is used not only for producing a high temperature, but also to produce oxidizing and reducing effects. The oxidizing flame aids in adding oxygen to the substance heated and the reducing flame abstracts it.

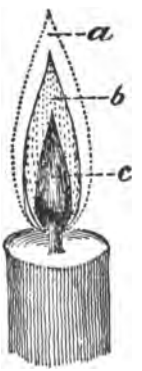


FIG. 90.
Candle Flame.

A luminous flame, such as is produced by a candle or a Bunsen burner, with the airholes at the foot of the tube closed, consists of (*c*) an inner, non-luminous cone (Fig. 90) containing unignited gas, (*b*) a luminous envelope surrounding this, in which there is partial combustion of the gas passing out from the non-luminous cone, and an outer purplish mantle.

Because protected from the air by the outer mantle, the gas in the luminous inner cone is not entirely consumed. The available oxygen combines with the easily combustible hydrogen, while the carbon of the gas is separated in extremely fine particles. These are at a high temperature and are, therefore, incandescent. In this condition, carbon is an active reducing agent, combining with oxygen readily, abstracting it for this purpose from any oxygen-bearing compound with which it is brought in contact. Consequently,

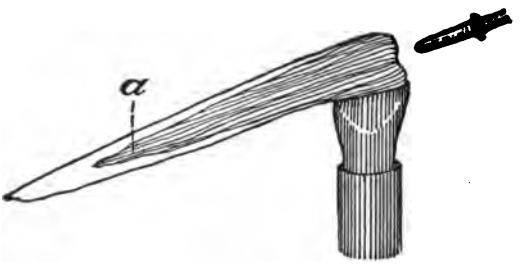


FIG. 91.—Reducing Flame.

this portion of the flame exerts a *reducing action* upon anything within its sphere. In the outer mantle, there is an abundance of oxygen. This combines with the carbon particles as they pass out from the luminous envelope, forming, at first, carbon monoxide, CO. This unites with more oxygen forming carbon dioxide, CO_2, and giving a blue flame. Since the temperature in this portion of the flame is very high and there is an abundance of oxygen present, substances subjected to its action are *oxidized.*

The use of the blowpipe accentuates the effect of the different portions of the flame and serves to direct it upon the particle to be tested.

To produce the reducing flame (R.F.), the blowpipe jet is placed at the edge of the burner flame near its base, and a gentle current of air is blown (Fig. 91). This deflects the flame without mixing too much oxygen with it—and it remains luminous. Its most energetic part is near the end of the luminous cone (*a*).

The oxidizing flame (O.F.) is produced by passing the tip of the blowpipe into the flame a short distance (Fig. 92) and blowpiping strongly, but steadily. A sharp-pointed, non-luminous flame results, with an

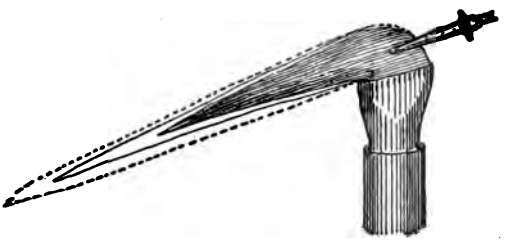


FIG. 92.—Oxidizing Flame.

inner blue cone. The most effective oxidizing area is just beyond the tip of the blue cone.

Before attempting to use the blowpipe for producing oxidizing and reducing effects, the two flames should be practiced with until they can be manipulated with certainty. The reducing flame is the most difficult to use successfully. It must be maintained unchanged for some time and the assay must be completely enveloped in it to secure satisfactory results. Otherwise, oxidation may ensue. In order to test one's ability to reduce with the blowpipe flame, a little borax should be melted in a small loop made at the end of a platinum wire. It will form a colorless glass. Into this should be introduced a tiny grain of some

manganese compound. If the borax with the added manganese is heated in the oxidizing flame, an amethyst-colored glass will result. This, if heated in the reducing flame, will again become colorless, but the color will return if the assay is touched by the oxidizing flame. When the color can be made to disappear and reappear at will, the proper amount of skill for the manipulation of the flames will have been attained.

Use of the Closed Tube.—The closed glass tube is used to discover whether a substance contains water or not, to detect its volatile constituents, and to discover the nature of its decomposition products. It is also employed in the observation of certain other characteristic changes in a substance produced by heating to a high temperature.

The material to be tested is powdered and slid into the tube with the help of a little, narrow paper trough, which is long enough to reach nearly to its bottom. The tube is then tapped to settle the material and the end containing the assay is heated, at first gently, later more vigorously, even to redness, either in the burner flame or in the flame produced by the blowpipe.

WATER is indicated by the condensation of little drops on the upper, cooler portion of the tube. If the water, when tested with litmus paper, reacts acid, a volatile acid (H_2SO_4, HCl, HNO_3 or HF) is indicated. If it reacts alkaline, ammonia has been evolved.

GASES.—The character of the gases evolved is best recognized by their color and odor.

(*a*) *Hydrogen sulphide* (H_2S) is recognized by its odor. It indicates a sulphide containing water.

(*b*) *Nitrogen peroxide* (N_2O_4) is recognized by its reddish-brown fumes and its characteristic odor. It indicates a nitrate or a nitrite. In the case of HNO_3, the reaction is $2HNO_3 = O + H_2O + 2NO_2$.

(*c*) *Hydrofluoric acid* (HF) attacks the glass of the tube and etches it. Its presence in the assay indicates a fluoride.

SUBLIMATES or coatings may be deposited in the cooler portion of the tube.

(*a*) If *white*, they may indicate ammonia salts, antimony trioxide, arsenic trioxide or tellurium dioxide.

(*b*) If *gray* or *black*, they indicate arsenic, mercury or tellurium.

(*c*) If *black, while hot*, and *reddish-brown, when cold*, antimony sulphide; and if *reddish-brown, while hot*, and *reddish-yellow, when cold*, arsenic sulphide.

CHANGES OF COLOR are very characteristic for certain substances, the following being of greatest importance:

(*a*) From *white* to *yellow* and to *white* again on cooling: zinc oxide.

(*b*) From *white* to *brownish-red* and back to *yellow:* lead oxide.

(*c*) From *white* to *orange-yellow* and back to *pale yellow* when again cold: bismuth oxide.

(*d*) From *red* to *black* and *red* again when cold: mercuric and ferric oxides. The mercury oxide is volatile.

Use of the Open Tube.—The open tube is used when it is desired to treat the assay with a current of hot oxygen. It is charged in the same manner as the closed tube, the assay being placed about 12 mm.

from the end. The tube is then held in the forceps over the flame, care being taken to incline it slightly for the purpose of producing an upward current. By this means, the following substances are easily detected:

Sulphur is detected by the choking odor of SO_2.

Arsenic yields a white volatile sublimate, which disappears upon heating.

Antimony gives white fumes which may partly condense on the cooler portion of the tube as a white sublimate and partly escape from its end. The sublimate is only slightly volatile.

Mercury yields globules of mercury.

Tellurium yields a white sublimate, which, when heated, fuses to colorless drops.

Selenium gives a sublimate which is white or steel-gray near the assay (SeO_2) and red at a greater distance (SeO_2 and Se). The odor of the volatile metal is exceedingly disagreeable. If the tube is allowed to discharge through the flame, it will produce a blue color.

The Use of the Charcoal.—A shallow depression is made near one end of a piece of charcoal, the powdered assay placed in this, and the blowpipe flame played upon it, while the charcoal is held in a tilted position by the left hand. If the assay decrepitates when heated, it should be moistened with a drop of water. The principal phenomena to be noted are: volatilization, fusibility, decrepitation, deflagration, odor, reduction and the production of sublimates.

Volatilization.—The substance vaporizes and disappears.

Fusibility.—The substance melts entirely or par-

tially in the different parts of the flame, some substances fusing easily and others only with great difficulty.

Decrepitation.—The substance flies to pieces when heat is applied, indicating decomposition or the presence of water, or included gases.

Deflagration.—The substance suddenly burns with little explosions characteristic of *nitrates.*

Reduction and Sublimation.—When heated on charcoal with the R.F., some substances may easily be *reduced* to the metallic state, others are reduced with difficulty. Thus, $2PbO+C=Pb_2+CO_2$. Reduction takes place most readily if the assay is powdered and mixed with about four times its volume of dry sodium carbonate (Na_2CO_3). Thus:

$$2PbS+2Na_2CO_3+C=2Na_2S+Pb_2+3CO_2.$$

In cases of great difficulty, a little potassium cyanide [1] (KCN) or borax ($Na_2B_4O_7\cdot 10H_2O$) added to the mixture will frequently hasten the result. In any case, the heat must be applied until nearly all the assay sinks into the charcoal.

When sufficiently heated, some substances yield a globule of metal, others are completely volatilized, others yield fumes, produced by the oxidation of portions of the assay, while yet others are partly reduced to a globule of metal and partly volatilized. Thus, during the reduction of PbS, some of the lead may be oxidized according to the reaction:

$$PbS+Na_2CO_3=Na_2S+PbO+CO_2,$$

[1] Potassium cyanide must always be used with care, as it is a deadly poison, even in minute quantities.

and a portion of the oxide may settle on the coal. When fumes are produced, they are deposited upon the cooler portions of the charcoal in the form of sublimates which possess characteristic properties.

Gold, silver, and *copper* compounds yield globules of metal without sublimates. The metals are separated for examination by cutting out the charcoal beneath the assay, and crushing the mass with water in a small mortar. Upon pouring off the water, the metal remains as spangles, grains or powder. The silver is recognized by its color and by the fact that its solution in nitric acid yields a white precipitate upon the addition of a drop or two of hydrochloric acid. Copper and gold have nearly the same color, but copper dissolves in nitric acid while gold is insoluble. Addition of an excess of ammonia to the solution of copper gives a characteristic, deep blue color.

Iron, nickel, and *cobalt* give gray infusible powders which are magnetic, but yield no sublimates.

Molybdenum, tungsten, and some of the rarer metals give gray powders that are non-magnetic and no sublimates.

Antimony yields copious white fumes, forming a volatile white sublimate (Sb_2O_3), which becomes black when touched with the R.F. When touched by the tip of the O.F., it will volatilize and color the flame yellowish-green. The metallic bead, when dropped upon a sheet of glazed paper, breaks into a number of smaller ones.

Arsenic volatilizes completely and consequently yields no globule of metal. It gives abundant white fumes which form a white sublimate and have a garlic odor. The flame at the same time is colored blue.

Bismuth yields a reddish-white, brittle globule and an orange-yellow sublimate which becomes lemon-yellow when cold.

Cadmium gives brown fumes in the O.F. and yields a reddish-brown sublimate, while the flame is colored dark green.

Lead yields a gray malleable bead, and incrusts the charcoal with a lemon-yellow sublimate near the assay. The flame at the same time is colored blue. The yellow incrustation is composed of lead oxide.

Molybdenum gives a crystalline incrustation which is yellow when hot and white when cold. When touched by the O.F. it becomes dark blue, and when heated for a longer time dark copper red. The blue incrustation may be molybdenum molybdate ($MoMoO_4$) and the red one, molybdenum dioxide (MoO_2).

Selenium yields brown fumes, but the sublimate which is near the assay is gray. When heated with the reducing flame, it disappears and the charistic bad odor is evolved. The flame becomes blue.

Tellurium coats the charcoal with a white sublimate bordered by dark yellow. The coating disappears in the R.F., which acquires a green color.

Tin gives a white globule which is malleable and a yellowish-white coating, turning white upon cooling. When moistened with a drop of $Co(NO_3)_2$ solution and heated in the O.F., its color changes to blue-green.

Zinc burns in the O.F. with a bluish-white color and evolves thick white fumes which condense as a yellowish sublimate. This becomes white on cooling, and, when moistened with a drop of cobalt nitrate and again heated, it turns grass-green (compare tin).

Other metals also give characteristic reactions on charcoal, but the above are the most important.

Use of the Beads.—The beads are used for the detection of metals that produce characteristic, colored compounds when fused with borax or microcosmic salt or some other reagent. A piece of platinum wire fused into a glass rod serves as a support. The end of the wire is bent into a little loop. This is moistened and plunged into powdered borax, microcosmic salt or other reagent and then heated carefully until the adhering material is fused to a clear glass. New material is added by dipping the loop again and again into the powdered salt and heating until the globules of glass are large enough to fill it completely. A tiny portion of the material to be tested is taken up by heating the bead and pressing it while still soft upon a tiny bit of the powdered assay, which has been placed in a clean watch-glass. The bead containing the substance is then heated with the O.F. and afterward with the R.F. and the phenomena resulting are carefully observed. If the reduction is difficult, a little stannous oxide or chloride will hasten it. If the bead becomes opaque because saturated with the assay, a portion is jerked off while it is hot and it is built up again by the addition of more of the reagent.

In some cases, compounds other than the oxides do not yield the characteristic beads of the metallic oxides. Therefore, it is safer in all cases when testing by the bead reaction, to first roast the substance by gently heating on charcoal with the O.F. to drive off its volatile constituents.

The colors of the most characteristic beads of metallic oxides are tabulated on the opposite page:

COLORS OF BORAX BEADS

Oxidising Flame.			Reducing Flame.	
Hot.	Cold.		Hot.	Cold.
Yellow or red	Grass-green	Chromium	Green	Emerald-green
Blue	Blue	Cobalt	Blue	Blue
Green	Blue	Copper	Colorless	Reddish-brown, opaque
Colorless	Colorless	Didymium	Rose	Rose
Yellow or red	Colorless or yellow	Iron	Bottle-green	Bottle-green
Violet	Reddish-violet	Manganese	Colorless	Colorless
Yellow or red	Colorless to opalescent	Molybdenum	Brown	Opaque-brown
Violet	Reddish-brown	Nickel	Gray	Gray
Colorless	Colorless	Columbium	Colorless or gray	Colorless or gray
Colorless or yellow	Colorless	Titanium	Yellow or brown	Yellow or brown
Colorless or yellow	Colorless	Tungsten	Yellow	Yellow-brown
Yellow or red	Colorless or yellow	Uranium	Pale green	Pale green to nearly colorless
Yellow	Green-yellow, or nearly colorless	Vanadium	Brownish-green	Emerald-green

COLORS OF MICROCOSMIC SALT BEADS

Oxidising Flame.			Reducing Flame.	
Hot.	Cold.		Hot.	Cold.
Reddish-green	Emerald-green	Chromium	Reddish-green	Emerald-green
Blue	Blue	Cobalt	Blue	Blue
Green	Blue	Copper	Dirty green	Green, or opaque-red
Colorless	Colorless	Didymium	Colorless	Blue
Yellow or red	Colorless, yellow or brown	Iron	Yellow or red	Nearly colorless
Violet	Violet	Manganese	Colorless	Colorless
Green	Faint yellowish-green	Molybdenum	Dirty green	Green
Reddish to brown	Yellowish to reddish	Nickel	Reddish	Yellowish to reddish-yellow
Colorless	Colorless	Columbium	Blue or brown	Blue or brown
Skeleton	Skeleton	Silica	Skeleton	Skeleton
Colorless	Colorless	Titanium	Yellow	Violet
Colorless	Colorless	Tungsten	Dirty green-blue	Blue
Yellow	Yellow-green to colorless	Uranium	Dirty green	Bright green
Dark yellow	Light yellow to colorless	Vanadium	Brownish-green	Emerald-green

Cobalt is the only metal which produces the same colored bead under all conditions. This is a beautiful blue bead. Other oxides give blue beads under some

one or more conditions, but under other conditions their beads have other colors.

The *cold* bead of chromium oxide is always green and the *oxidized* bead of manganese is always violet.

Flame Coloration.—Many substances impart a distinct color to the non-luminous flame of the burner or the blowpipe. Frequently, these colors are best seen after the substance in powdered form has been moistened with hydrochloric acid, as the chlorides are usually more volatile than other compounds. In the case of silicates, it is often advisable to mix the powdered assay with an equal volume of *powdered gypsum*. In testing for flame coloration a very small particle of the substance, or its moistened powder, or of the mixture of the substance and gypsum is held in the flame by the aid of the platinum loop which has been cleaned by dipping into HCl, and heated repeatedly until it no longer colors the flame.

When several different flame-coloring elements are present in the assay, the stronger color may mask the fainter one, and, therefore, some means must be made use of to shut off the brighter color, while allowing the fainter one to persist. This is usually accomplished by viewing the flame through some medium (a screen) that is transparent to the faint rays and opaque to the brighter ones. In other cases, two flames which are really different in color appear of nearly the same tint to the unaided eye. In this case, the screen is again used to cut off certain rays that are common to the two colors, when the remaining rays may be different enough to be distinguishable. The screens most frequently used for this purpose are pieces of colored glass, which are held close to the eye.

Red glass absorbs all but red rays. Blue glass stops certain red and green rays and all the yellow ones. Great difficulty is sometimes experienced in securing glass exhibiting pure colors, so that in most cases it is more convenient to use transparent celluloid films that have been manufactured expressly for the examination of colored flames. These films are given the tints that are most useful for the purpose desired. Care must be taken in using them, however, since celluloid is highly inflammable.

For more accurate work the spectroscope is often employed. The use of this depends upon the fact that each substance, when in the form of gas, emits light composed of one or more rays of definite wave lengths, and the spectroscope separates these so that each may be identified.

The most characteristic colors imparted to the blowpipe flame are:

Red by lithium, strontium, and calcium. Sodium salts obscure the lithium flame and barium salts the strontium and calcium flames.

Yellow by sodium.

Green by most copper compounds, thallium, barium, antimony, phosphoric acid, boric acid, molybdic acid, and nitric acid. The flame of phosphoric acid is bluish-green, the flames of boric acid and barium are yellow-green, and those of molybdic acid and antimony are very faint. The copper and thallium flames are vivid greens. The nitric acid flame coloration is bronze-green and it exists as a flash only.

Blue by copper chloride, copper bromide, selenium, arsenic and lead. The arsenic flame is faint.

The selenium and the copper chloride flames are brilliant azure-blue.

Violet by potassium, caesium and rubidium. Sodium and lithium salts obscure the reaction.

Detection of Certain Elements in the Presence of Others.—In many cases, as has been stated, the color imparted to the flame by one substance entirely obscures that given it by another when the two are present in the same compound. Thus, the faint violet color of the potassium flame is obscured by the strong yellow of sodium and the brilliant red of lithium. When this is the case, the light is viewed through the proper screens and the different rays in this manner are differentiated. Since the flame tests afford the readiest means of detecting the alkalies and alkaline earths, considerable attention has been devoted to means of differentiating their flame colors. Among the methods proposed for this purpose is that based upon the use of blue and green glass screens.

Detection of the Alkalies and the Alkaline Earths.—The potassium flame is reddish-violet through blue glass, while the sodium flame is invisible or is blue; hence, the potassium flame is detected in the presence of sodium by viewing the mixed flame through a blue screen. Lithium is also detected in the presence of sodium with the aid of blue glass, since the lithium flame is violet-red when viewed through a blue screen. Since the flame colors of Li and K are so nearly alike when viewed through a blue screen, they cannot easily be distinguished. When viewed through a green screen, however, the Li flame is nearly invisible, while that of K is bluish-green. Through the green screen the Na flame appears orange.

If search is to be made for the alkaline earths, the assay is repeatedly moistened with sulphuric acid and placed in the hottest portion of the flame. After the alkalies are driven off, the flame will become yellowish-green, if barium is present; through green glass it will appear bluish-green. The assay is then repeatedly moistened with pure hydrochloric acid and again brought, while still moist, into the hottest portion of the flame. A red coloration, appearing after the yellowish-green barium flame has disappeared, indicates calcium or strontium or both. Through green glass the calcium flame appears green and the strontium flame faint yellow for an instant. Through blue glass calcium gives a faint greenish-gray and strontium a purple or rose color.

These phenomena exhibited by the alkalies and alkaline earths may be summarized as follows:

	Flame Color.	Through Blue Glass.	Through Green Glass.
Potassium	Violet	Reddish-violet	Bluish-green
Sodium	Yellow	Blue to invisible	Orange-yellow
Lithium	Carmine	Violet-red	Invisible
Barium	Yellow-green		Bluish-green
Calcium	Yellow-red	Green-gray	Green
Strontium	Scarlet	Purple	Faint yellow

The detection of the alkalies in silicates is accomplished by fusing the powdered assay on platinum wire with a little pure gypsum. If the alkaline earths are sought for, the assay is fused with sodium carbonate on platinum wire, or better, on a piece of platinum foil. The fused mass is then extracted with water and the residue treated with hydrochloric acid. Silica will be precipitated, leaving in the solution a mixture

of sodium chloride and the chlorides of the alkaline earths. The solution is then tested in the flame with the aid of a clean platinum wire.

The Copper Test.—An almost certain test for copper and for chlorine is afforded by the difference in the color imparted to the flame by copper chloride and most other copper salts.[1] Several substances besides copper give green flames, but in the case of copper alone the color of the flame is changed to sky-blue by touching the assay with HCl, or a chloride.

Special Tests.—A few tests with special reagents are so characteristic for certain elements that they are specific:

Tests with Na_2CO_3.—When a powdered substance containing S is fused with four times its volume of dry Na_2CO_3 and heated intensely for some time on charcoal, the residue, when placed on a silver coin and moistened with water or hydrochloric acid, will yield a black or brown stain. This reaction is due to the production of Na_2S, which is soluble. The solution containing the sulphide reacts with the silver, producing insoluble Ag_2S, which is brown or black. Thus: $Na_2S+Ag_2+H_2O+O=Ag_2S+2NaOH$. Sulphides and sulphates are distinguished by roasting the compound on charcoal without Na_2CO_3. Sulphides yield the sulphur-dioxide odor.

Manganese and *chromium* compounds, fused with Na_2CO_3 (especially when a little niter is added), yield colored masses—the manganese compound a bright green mass (Na_2MnO_4) and the chromium compounds a bright yellow mass (Na_2CrO_4). In the case of the manganate, the reaction may be

$$MnO_2+Na_2CO_3+O=Na_2MnO_4+CO_2.$$

Tests with the Cobalt Solution.—Certain metallic oxides, when moistened with a few drops of a solution of crystallized cobalt nitrate dissolved in ten parts of water, and heated, yield distinctive colors that may often serve as aids in their detection. The assay is powdered, moistened with a drop of the cobalt solution, and placed on charcoal and heated intensely. Compounds containing *alumina* yield a mass of a *blue* color, without luster. A few other substances may also give blue masses, but the materials are fused and, consequently, show a glassy luster. *Magnesium* compounds give a *pink* color.

In testing for other substances, it is necessary first to obtain their oxides. This is done by roasting on charcoal until a distinct sublimate is produced. This sublimate is moistened with a drop of the solution and heated gently by the O.F. Under these conditions, the white *zinc sublimate* (ZnO) changes to a bright *yellowish-green* and *tin oxide* (SnO_2) to a *bluish-green.*

Tests with Acid Potassium Sulphate.—Hydrogen potassium sulphate ($HKSO_4$), when fused with a powdered substance in a closed tube, may cause the evolution of gases. For example:

$$2HKSO_4+CaF_2=K_2SO_4+CaSO_4+2HF,$$

which in many cases may easily be recognized.

Nitrites and *nitrates* yield reddish-brown fumes (NO_2) with the characteristic odor of nitrogen peroxide.

Chlorates yield a yellowish-green explosive gas.

Iodides yield a violet gas, which colors blue a paper soaked in starch paste, when a little MnO_2 is added to the $HKSO_4$.

Bromides yield a reddish-brown gas (Br), turning starch paste yellow, when MnO_2 is mixed with the $HKSO_4$.

Chlorides yield hydrochloric acid (HCl), recognized by its odor and the voluminous white fumes it forms with ammonia.

Sulphides yield hydrogen sulphide (H_2S) with its characteristic odor. This gas blackens paper moistened with lead acetate.

Fluorides yield hydrofluoric acid (HF) gas, which has a pungent odor and etches glass. The etching is due to the reaction between the SiO_2 of the glass and the HF. Thus, $SiO_2+4HF=SiF_4+2H_2O$. The SiF_4 is volatile and is driven up the tube, leaving tiny pits from which the SiO_2 was taken. This reaction is best seen by heating the assay with four times its volume of the reagent and then cleaning and drying the tube.

The reaction is more delicate if the finely powdered assay is mixed with microcosmic salt and heated in an open tube. When the salt is heated, it breaks up, yielding $NaPO_3(HNa(NH_4)PO_4 \cdot 4H_2O = NaPO_3 + NH_3 + 5H_2O)$ which reacts with the fluoride as follows:

$$CaF_2+NaPO_3+H_2O=CaNaPO_4+2HF.$$

By Reduction with Metallic Zinc and Hydrochloric Acid certain metallic salts yield colored solutions which are characteristic. The substance to be tested is powdered and mixed thoroughly with sodium carbonate and niter, and the mass is slightly moistened and placed in a little spiral at the end of a fine platinum wire. After fusion, it is dissolved in a little water, a few drops of hydrochloric acid are added and a strip of zinc or tin, or a few grains of the metal, are then placed in

the solution. The hydrogen, evolved by the contact of the metal and the acid, reduces the oxides and the solution becomes colored. The most important oxides detectable by this method are:

Molybdenum, which gives a blue, then green, and finally a blackish-brown solution.

Tungsten, a blue, then brown or copper-red solution.

Vanadium, a blue solution.

Columbium, a blue or brown solution which loses its color on addition of water.

Chromium, a green solution.

Titanium, a violet solution.

In the case of titanium the reactions are:

$$TiO_2+2Na_2CO_3=Na_4TiO_4+2CO_2;$$
$$Na_4TiO_4+8HCl=TiCl_4+4NaCl+4H_2O;$$
$$TiCl_4+H=TiCl_3+HCl.$$

The $TiCl_3$ produces the violet solution.

Magnesium ribbon is generally employed as an aid in the detection of phosphorus. The powdered assay is placed in the bottom of a closed glass tube with a piece of magnesium ribbon about 5 mm. long, so that the powder is in close contact with the metal. This is then heated intensely until partial fusion ensues. The completion of the reaction is known by the formation of a brown or black glass, which is the phosphide of magnesium. Upon crushing the tube and moistening its contents with water the characteristic odor of of phosphine is perceived (the odor of wet phosphorus matches).

Hydrochloric acid furnishes the readiest test for carbonates. If the powdered substance is heated gently with dilute acid in a test tube, a brisk efferves-

cence will result if it contains the carbonic acid radical. Sometimes the effervescence can be detected by holding the mouth of the test tube to the ear, even when the escape of gas cannot be seen. The gas (CO_2) is colorless, and when allowed to bubble through lime water will cause turbidity.

IV

CHARACTERISTIC REACTIONS OF THE MORE IMPORTANT ELEMENTS AND ACID RADICALS

Aluminium (p. 147).—Fusible minerals cannot be satisfactorily tested for Al by the method using $Co(NO_3)_2$, since cobalt imparts a blue color to all glasses.

Since zinc silicates yield the same color reaction with $Co(NO_3)_2$ as do infusible aluminium compounds, the presence of aluminium in silicates cannot be assured unless the absence of zinc is proven.

Antimony (pp. 135, 136, 138, 143).—In the presence of lead or bismuth, the assay is heated on charcoal with fused boric acid, which dissolves the lead and bismuth oxides, while the antimony oxide coats the charcoal.

When antimony and lead are present in the same compound, the antimony oxide forms a white incrustation surrounding a dark orange-yellow incrustation of lead antimonate.

Arsenic (pp. 135, 136, 138, 143).—Arsenic in arsenates and arsenites may usually be detected by heating the powdered assay with six times its volume of a mixture of equal parts of Na_2CO_3 and KCN (or powdered charcoal) in a dry closed glass tube, when an arsenic mirror will form on the cold part of the tube. This may be further tested by breaking off the end of the tube and heating the mirror in the burner

flame. The escaping fumes will have the characteristic garlic odor. If allowed to pass through the flame, they will tinge it violet.

If there is doubt as to whether a white sublimate on charcoal contains arsenic, or if it is desired to test for arsenic in the presence of antimony, a little of the coating which is farthest away from the assay may be scraped from the surface of the charcoal and placed in a narrow glass tube and heated. If arsenic oxide is present in the coating, the arsenic mirror will form on the walls of the cooler part of the tube.

Barium (pp. 143, 145).—Before applying the flame test for barium, silicates should first be fused with four parts of dry Na_2CO_3 and charcoal in a loop of platinum wire, crushed, placed in a test tube, treated with a few cc. of dilute HNO_3 and evaporated to dryness. After cooling, warm with a very little HCl, then add about 10 cc. of water and filter off the insoluble silica. To the filtrate add a few drops of H_2SO_4, collect the precipitate on a small filter, and test with the flame (see also under *Calcium*).

Bismuth (pp. 135, 139).—A very characteristic test is the following: The powdered substance is mixed with twice its volume of a mixture composed of equal parts of KI and flowers of sulphur, and heated in the R.F. on charcoal. If Bi is present, a brick-red iodide of bismuth will form a coating at some little distance from the assay. This test serves to distinguish between Pb and Bi, both of which yield yellow oxide coatings when tested on charcoal.

Boron (p. 143).—To obtain the green flame in the case of most compounds containing boron, it is sufficient to moisten the fine powder with a drop of

strong sulphuric acid and introduce a small quantity into the flame on a platinum wire. The flame will be colored green, but only for a moment. More resistant compounds, like the silicates, must be fused with a flux composed of one part of powdered fluorspar and four parts of $KHSO_4$ before the green coloration can be obtained. The HF generated decomposes the silicate and sets free the boron.

In the presence of copper compounds or phosphates, which also give green flames, the finely-powdered assay is moistened on platinum foil with sulphuric acid. The excess of acid is then removed by heating, and the powder mixed into a paste with glycerine and a little sodium carbonate. When heated in the flame, the sodium will mask the green color due to the copper and phosphorus, but not that produced by boron.

If boron compounds are fused with Na_2CO_3 and then treated with dilute HCl, a drop of the resulting solution will cause turmeric paper to turn reddish-brown after being dried at 100°. If moistened with ammonia, the color changes to black.

Bromine (p. 148).—Solutions of bromides, produced by dissolving in water or HNO_3 (after fusion with Na_2CO_3 if insoluble otherwise), will yield with a drop or two of silver nitrate solution a yellowish precipitate of AgBr, which is soluble in ammonia. If this precipitate is mixed with Bi_2S_3 and heated in a closed tube, a yellowish sublimate of $BiBr_3$ will result. (Compare *Chlorine* and *Iodine*.)

Cadmium (p. 139).—When present with Pb or Zn, it is often difficult to recognize the cadmium coating on charcoal. In this case, the coating may be scraped

from the coal and heated very gently in the closed tube. A yellow sublimate of cadmium oxide will form just above the assay. On further heating, this will be masked by the zinc and lead oxides.

Calcium (pp. 143, 145).—Calcium in silicates and other insoluble compounds may be detected by the same method as that for the detection of barium. The precipitate of $CaSO_4$, however, is dissolved when heated with a large volume of water.

Carbonates.—See page 149.

Chlorine (pp. 146, 147, 148).—Chloride solutions, when treated with $AgNO_3$, yield a white precipitate of AgCl, soluble in ammonia. When exposed to the light, it darkens. If mixed with Bi_2S_3 and heated in a closed tube, a white sublimate of Bi_2Cl_3 is formed. (Compare *Bromine* and *Iodine*.)

Chromium (pp. 141, 146, 149).—In the presence of large quantities of iron, copper, etc., the powdered assay (if not a silicate) is mixed with double its volume of equal parts of Na_2CO_3 and K_2NO_3 and fused on a platinum spiral in the O.F., when an alkaline chromate will be formed. This, dissolved in water and boiled with an excess of acetic acid, yields a solution which gives a yellow precipitate of $PbCrO_4$ with a few drops of lead acetate.

Silicates containing small quantities of chromium and large quantities of copper and iron should first be fused on charcoal with a mixture of one part of sodium carbonate and a half part of borax. The clear glass thus produced is dissolved in hydrochloric acid and the solution evaporated to dryness. This is then treated with water, filtered, and the filtrate boiled with a few drops of nitric acid to oxidize the

iron. By the addition of ammonia, the chromic and other oxides are precipitated. The precipitate is collected on a filter, washed, and treated as above, or tested with the borax bead.

Cobalt (p. 141).—For the detection of cobalt in the presence of iron or nickel, see under those metals.

Columbium (pp. 141, 149).—When a compound containing columbium is fused with five parts of borax on platinum foil, dissolved in concentrated HCl and diluted with a little water, the solution becomes blue when boiled with the addition of granulated tin. The color does not change to brown on continued boiling. It disappears, however, when diluted with water. If titantium is present in the same solution, its color will be first violet, then blue. Tungsten, which gives a blue solution under the same conditions, can be distinguished from columbium by the bead test. If, instead of tin, the solution is boiled with zinc, its color changes rapidly from blue to brown.

Or, the finely-powdered substance may be fused in a test tube or crucible with ten parts $KHSO_4$, and then digested with cold water for a long time. If columbium is present, an insoluble white residue will be left. This, if collected on a filter, washed, and then treated in a test tube with hot concentrated HCl, will yield the blue solution when boiled with granulated tin.

Copper (pp. 141, 143, 146).—A very delicate test for soluble copper compounds is to dissolve them in HCl or HNO_3, dilute with water and add ammonia in excess. A deep purple-blue solution of $CuCl_2 \cdot 6NH_3$ or $Cu(NO_3)_2 \cdot 6NH_3$ will result.

Fluorine (pp. 135, 148).—If the mineral to be tested is a silicate, its powder is mixed with four parts of

fused microcosmic salt and this mixture is heated in a closed tube. If fluorine is present, the glass above the assay will be etched by the HF produced. At the same time, a ring of SiO_2 is deposited in the cool portion of the tube in consequence of the reaction

$$3SiF_4+2H_2O=2H_2SiF_6+SiO_2.$$

Upon heating, the ring moves up the tube to a cooler portion.

Gold (p. 138).—The metal is best detected by treatment with aqua-regia of the metallic bead, produced by fusion with Na_2CO_3 on charcoal. This yields a light-yellow solution, which, when taken up on a filter paper and moistened with stannous chloride, gives the " purple of Cassius."

Or, if the mineral is to be tested for free gold, it is powdered and treated with aqua-regia and the solution diluted and filtered. The filtrate is evaporated nearly to dryness, diluted with water and a few drops of a solution of ferrous sulphate are added. If gold is present in small quantity only, the solution will be colored bluish or purple. If the gold is present in larger quantity, the metal will be precipitated as a brown powder.

Free gold may also be detected by powdering the substance until all will pass through a fine sieve. Brush the material adhering to the sieve and add to the powder. Then place in a basin containing a little mercury ($\frac{1}{2}$ cc.) and immerse the basin and its contents in water. Shake the basin gently with a rocking motion and gradually allow the rock powder to escape. The gold will fall to the bottom and amalgamate with the mercury. After the mass has been reduced to a

small volume, transfer to a mortar and grind in a gentle stream of water, until nothing but the amalgam is left. Then place in an iron spoon and heat in the open air until all the mercury is driven off; or the amalgam may be placed in a shallow cavity on charcoal and heated with a small blowpipe flame until all the mercury volatilizes. The residual gold may be collected into a globule by placing a little borax or sodium carbonate in the cavity and heating until quiet fusion takes place.

When driving off the mercury from the amalgam extreme care must be taken not to breathe its fumes since they are poisonous. The operation should not be performed in a closed room.

Iodine (p. 147).—Substances containing iodine, when fused in a glass tube with $KHSO_4$ and MnO_2, yield a vapor which is recognized as that of iodine by its violet color. In the presence of other halogens, iodine may be detected by mixing the powdered substance with BiS_3 (prepared by fusing together small quantities of bismuth and sulphur) and heating in a closed tube or on charcoal before the blowpipe. If iodine is present, a red sublimate of bismuth iodide is produced. (Compare *Chlorine* and *Bromine*.)

Iron (pp. 135, 138, 141).—To distinguish ferrous and ferric conditions, the assay is added to a borax bead containing copper. If the iron is in the ferric condition, the bead will be bluish-green; if in the ferrous condition, it will contain red streaks of cuprous oxide.

In the presence of easily fusible metals like lead, tin, zinc, etc., the substance is heated on charcoal with borax in the R.F. The easily reducible metals do not become oxidized and, consequently, are not

absorbed by the glass. The glass is separated from the metallic bead, and is heated on a fresh piece of charcoal in the R.F., when it acquires the characteristic bottle-green color produced by iron, and becomes vitriol-green on addition of tin.

In the presence of cobalt, the blue color of the cobalt bead masks the green of the iron bead. In this case, iron is detected by heating the blue glass on platinum wire in the O.F. sufficiently long to convert all the iron into peroxide. With very little iron present, the bead is green when hot, and blue when cold; with more iron the bead is dark green when hot, and pure green when cold, this latter color resulting from a mixture of the yellow iron and the blue cobalt colors.

Manganese colors the borax bead in the O.F. red. Upon reduction with tin on charcoal, the bead becomes bottle-green. If cobalt also is present, the bead produced in the O.F. is dark violet. In the R.F. it becomes green when hot and blue when cold.

Lead (pp. 135, 139, 143).—The coating of lead oxide resembles very closely that of bismuth. The two may be distinguished by the proceeding described under bismuth. The iodide of lead is lemon-yellow.

Lithium (pp. 143, 144, 145).—In the case of silicates, before testing for flame coloration, it is advisable to mix the powder of the assay with one part of fluorspar and one and a half parts of $KHSO_4$ and form into a paste with a drop of water. If boron is present, the flame is at first green, then red. The presence of phosphoric acid is shown by the production of a green flame together with the red one. This is especially noticeable after moistening the assay with sulphuric acid.

Magnesium (p. 147).—The $Co(NO_3)_2$ test for magnesium is applicable only to white or colorless minerals and is by no means conclusive. The most satisfactory test is that employed generally in ordinary qualitative analysis, viz., precipitation with the aid of sodium phosphate (Na_3PO_4). The powdered mineral, if insoluble in acids, is fused with Na_2CO_3, powdered, dissolved in a few cc. of dilute HNO_3 and evaporated to dryness. It is then dissolved in 2 or 3 cc. HCl and warmed for a few minutes. There is next added about 10 cc. of water and the solution is boiled and filtered to remove silica. The filtrate is heated to boiling and NH_4OH is added to slight excess to precipitate iron and aluminium. This is now filtered and the filtrate is boiled again, and to it is added some ammonium oxalate to separate calcium. After allowing it to stand for ten or fifteen minutes, the calcium oxalate is removed by several filtrations until the filtrate is clear. To the filtrate a solution of sodium phosphate and strong ammonia are added. If magnesium is present after standing for some time, a fine white crystalline precipitate of $NH_4MgPO_4 \cdot 6H_2O$ will form.

Manganese (pp. 141, 146).—Manganese compounds soluble in HNO_3 are readily detected by oxidation with persulphates. The procedure is to dissolve in a few cc. of moderately dilute HNO_3 (sp.gr. 1.2), add about one-half its volume of dilute solution of $AgNO_3$ and a few drops of ammonium persulphate (200 gr. $(NH_4)_2S_2O_8$ to one liter of water) and gently heat. The manganese will be oxidized to permanganic acid, which is purple. The reaction is

$$2Mn(NO_3)_2+5(NH_4)_2S_2O_8+8H_2O$$
$$=5(NH_4)_2SO_4+5H_2SO_4+4HNO_3+2HMnO_4.$$

Compounds that are insoluble in HNO_3 must first be fused with Na_2CO_3 on charcoal.

Mercury (p. 135).—In the presence of sulphur, chlorine, iodine and a few acids, the assay is best heated with dry Na_2CO_3 in a closed glass tube. The acid combines with the sodium and the mercury sublimes.

Molybdenum (pp. 138, 139, 141, 143, 149).—The white coating of MoO_3 on charcoal, if touched with the R.F., is partly reduced, becoming blue. If heated by the O.F., some of it volatilizes, but some is reduced by the charcoal, forming a copper-red coating.

Small quantities of molybdenum are detected by treating the powdered assay with a little strong sulphuric acid on a platinum foil. After heating until most of the acid is evaporated, and then cooling, the resulting mass becomes blue, particularly after being repeatedly breathed upon, or after being moistened with alcohol and dried by heating.

Nickel (pp. 138, 141).—In the presence of Co, the color of the Ni borax bead is often masked. In such cases, a small portion of the mineral is fused in the R.F. to a globule. A fragment of borax "twice the size of the globule is placed beside it on charcoal and the two are heated by the O.F. The two globules will roll around under the flame in contact, but will remain quite distinct; any cobalt will be oxidized by the O.F. and be absorbed by the borax, which will become blue. If the mineral is placed upon a clean part of the coal and the treatment is continued with fresh portions of borax until all the cobalt has been oxidized and the borax no longer becomes blue, the nickel present will impart its characteristic violet and reddish-brown color to the borax." (Phillips.)

Nickel is best detected by treating its solution with dimethyl glyoxime ($(CH_3)_2C_2(NOH)_2$). The assay is dissolved in acid, after fusion with Na_2CO_3, if necessary, and the solution is neutralized with $(NH_4)OH$. Add one-half volume of dimethyl glyoxime solution, made by dissolving one part of the compound in 100 pts. of a 40 per cent. alcohol, and again add a little $(NH_4)OH$ to neutralize. A bright red crystalline precipitate will form if nickel is present, according to the reaction:

$$NiCl_2+2(CH_3)_2C_2(NOH)_2 = (CH_3)_2C_2(NOH)_2\cdot(CH_3)_2C_2(NO)_2Ni+2HCl.$$

Nitric Acid (pp. 135, 143, 147).—Nitric acid is best detected by dissolving the assay in dilute (1:1) H_2SO_4, cooling and adding to the solution in a test tube a few drops of a strong solution of $FeSO_4$ in water, holding the tube slanting and allowing the $FeSO_4$ to trickle quietly down its side and form a layer upon the acid solution. If nitrates are present, a brown ring will form at the contact of the two solutions.

Oxygen, in some of the higher oxides, may be detected by the liberation of chlorine when they are treated with HCl. This is particularly the case with the higher oxides of manganese, thus:

$$MnO_2+4HCl = MnCl_2+2H_2O+2Cl.$$

The chlorine is recognized by its color, its odor and its bleaching action.

Phosphoric Acid (pp. 143, 149).—In the test with magnesium ribbon, it is best to fuse the phosphates of Al and the heavy metals with two parts of Na_2CO_3 on charcoal, to remove and grind up the fused mass, and

then to ignite the powder with magnesium ribbon in a closed glass tube (Brush and Penfield).

If a small crystal of ammonium molybdate $(NH_4)_2MoO_4$ be placed on a phosphate and a little dilute HNO_3 be dropped upon it, the crystal will turn yellow in consequence of the production of ammonium phosphomolybdate $11(MoO_3)\cdot(NH_4)_3PO_4$. This test is available only for compounds that are soluble in HNO_3.

If the mineral is insoluble in HNO_3, it must first be fused with sodium carbonate on platinum wire. The bead is then dissolved in nitric acid and the solution when cold is added drop by drop to a little of an ammonium molybdate solution and allowed to stand without warming. If the assay contained the phosphoric acid radical, a yellow precipitate will be formed.

Potassium.—See pages 144 and 145.

Selenium (pp. 136, 139, 143).—Selenates and selenites must be reduced with sodium carbonate on charcoal before the peculiar odor is evolved.

Silicon (p. 141).—Small splinters of silicates yield an infusible skeleton of silica when heated in a bead of microcosmic salt. This floats around in the liquid bead as a particle with the shape of the original splinter or as a transparent flake. In some cases the original splinter remains undecomposed.

Many silicates decompose in strong HNO_4 or HCl with the production of a gelatinous mass of silicic acid. If the solution containing the gelatinous silica is evaporated to dryness, the silica becomes insoluble and remains as a residue when the mass is warmed with a little strong acid and digested with water.

In case of insoluble silicates it is necessary to fuse with Na_2CO_3 before proceeding with the test. The

fusion results in the production of a sodium silicate which is soluble in acids. The gelatinous precipitate will appear only after the acid solution of the fused mass is evaporated.

Silver.—See page 138.

Sodium.—See pages 143, 144 and 148.

Strontium (pp. 143, 145).—In the case of insoluble compounds treat as in the test for Ba. If both Ba and Sr are present in the final precipitate, the flame will first be crimson. Upon repeated moistening with HCl and heating, the Sr will gradually disappear and the green color of the Ba flame will be seen.

Sulphur (pp. 134, 136, 146, 148).—If a substance containing sulphur is heated with Na_2CO_3 on charcoal in the R.F. and the fused mass is transferred to a watch glass and moistened with water, the addition of a little dilute solution of ammonium molybdate, to which HCl has been added, will produce a blue color.

Sulphides are distinguished from most sulphates (except those containing water or the OH group) by heating in the O.F. The sulphides yield an odor of SO_2. The sulphates yield no odor. Another means of distinguishing between these two classes of compounds is as follows: The finely-powdered substance is fused with caustic potash (KOH), in a platinum spoon, or on a piece of platinum foil. The spoon or foil with its contents is thrown into water containing a strip of silver. If the silver remains quite white, the S is present as sulphate; if the silver becomes black, S is present as sulphide. Substances exercising a reducing action must, of course, not be present.

Tantalum cannot be recognized in the presence of **columbium** by any simple tests.

Tellurium (pp. 135, 136, 139).—A powdered tellurium compound, heated with Na_2CO_3 and charcoal powder in a closed glass tube and treated when cold with hot water, yields a purple-red solution of sodium telluride. This color will disappear if air is blown through the solution.

Tellurides may be detected by gently warming the finely-powdered substances with a few cc. of concentrated sulphuric acid. The solution will become carmine. After cooling, the addition of water will precipitate the tellurium as a blackish-gray powder, and the carmine color will disappear.

Thallium.—See page 143.

Tin (pp. 139, 147).—The reduction of tin compounds is accomplished fairly easily by mixing borax with Na_2CO_3 and treating with the R.F. on charcoal. The metallic tin thus obtained, when heated on charcoal by the O.F., yields a white incrustation which becomes bluish-green when moistened with cobalt nitrate and heated (see *Zinc*). Or, if warmed in a test tube with moderately dilute HNO_3, a white powdery metastannic acid (H_2SnO_3) will result.

If to a borax bead colored blue by a copper, a small quantity of tin compound be added and the R.F. be applied, the bead will turn brown.

Titanium (pp. 141, 149).—If iron is present, the bead of microcosmic salt in the O.F. has the iron color, and in the R.F. a blood-red color. When this is fused with tin in the R.F. on charcoal, the color becomes violet.

A very characteristic reaction is obtained as follows: Fuse on charcoal or platinum foil one part of the assay with 6 parts of Na_2CO_3 and a little borax. Then dissolve in a small quantity of concentrated

HCl (2–2.5 cc.) and add granulated tin. The hydrogen generated by the tin and HCl will reduce the $TiCl_4$ in the original acid solution to $TiCl_3$ and the solution will assume a violet color, especially after standing several hours.

For an extremely delicate test, fuse the powdered assay with Na_2CO_3 and borax, as in the color test with tin. If the fused mass is dissolved by heating in a test tube with 2 cc. of a mixture of equal parts of H_2SO_4 and water, and, after cooling, is diluted with about 10 cc. of cold water, the addition of a few drops of H_2O_2 to the diluted solution will produce a golden yellow or orange color if titanium is present.

Tungsten (pp. 138, 141, 149).—When present in small quantities, tungsten may be detected by fusing the assay with five or six times its weight of Na_2CO_3, extracting the resulting mass with water, filtering and adding to the filtrate strong hydrochloric acid. White tungstic oxide (WO_3) will be precipitated and this will become pale yellow on boiling. Upon acidification and boiling with a few particles of tin, a blue mixture of oxides results. The blue color *will not disappear* on the addition of water. (Compare tests for *columbium.*) On long-continued boiling, the color will change to brown (WO_2).

If the tungstate be decomposed by boiling with HCl, it is not necessary to fuse. Simply boil with acid until a light yellow precipitate (WO_3) is obtained. Then add tin and boil, and the blue color will result. This will change to brown on long-continued boiling (WO_2).

Uranium (p. 141).—If the uranium is so mixed with other metals that its characteristic bead is obscured,

dissolve the assay in HCl (first fusing with Na_2CO_3 or borax, if necessary), then nearly neutralize with ammonia and add a strong solution of Na_2CO_3 until precipitation ceases, then about half as much more and let stand for some time. The excess of Na_2CO_3 will dissolve the compound first precipitated. Filter, acidify the filtrate with HCl and boil until all the CO_2 is expelled. Then add ammonia in excess. If uranium is present, it will be precipitated as a gelatinous light yellow ammonium uranate, $(NH_4)_2U_2O_7$. To confirm, filter and test the precipitate in the bead of microcosmic salt.

Vanadium (pp. 141, 149).—Vanadium compounds, first roasted on charcoal and then fused with four parts Na_2CO_3 and two parts potassium nitrate on a platinum spiral, when extracted with hot water, filtered, acidified with acetic acid, and treated with a few drops of lead acetate, yield a pale yellow precipitate of $Pb_3(VO_4)_2$. This may be tested for vanadium in a microcosmic salt bead.

If the solution obtained by extracting the fused mass be filtered and acidified with HCl and well shaken with hydrogen peroxide, it will become reddish-brown or garnet color. If to the acidified solution metallic zinc be added, a bright blue color will result. This, however, will gradually become violet if the solution is left standing in contact with zinc.

If the substance is soluble in HCl or H_2SO_4, the solution thus produced will give a reddish-brown solution with hydrogen peroxide, or a blue solution when treated with zinc. The blue solution gradually changes to violet on continued action of the zinc. If the blue or violet solution is poured off the zinc and

a few drops of hydrogen peroxide be added, the characteristic brown color will result. For a more accurate determination of the presence of vanadium, add NH_4OH in excess to the acid solution and pass through it H_2S. The solution will become garnet if vanadium is present.

Zinc (pp. 135, 139, 147).—Infusible white or light-colored zinc compounds, when finely powdered and made into a paste with a drop of $Co(NO_3)_2$ solution, and then heated on charcoal by an O.F., assume a green color. But silicates of zinc when treated in this way with a hot flame often form a fusible cobalt silicate which is blue.

In the presence of antimony and tin, it is almost impossible to detect zinc by blowpipe tests, as all three metals yield nearly the same blowpipe reactions. However, the zinc sublimate when moistened with $Co(NO_3)_2$ solution and heated in the O.F. becomes grass-green, whereas the tin sublimate, under the same treatment, becomes blue-green.

Zirconium, in the absence of titanium, molybdates and boric acid, may be detected, after fusion of the assay with a little Na_2CO_3, by dissolving in a few drops of strong HCl and diluting with water to four times the volume, and then moistening with this dilute solution a piece of turmeric paper. When the paper is dried gently its color will change to reddish or orange if zirconium is present.

V

KEY TO THE DETERMINATION OF MINERALS

A "KEY" in mineralogy is a guide to aid in the determination of the name and nature of a mineral. The most serious objection to its use lies in the danger that the student will feel, when the name of the substance under examination is obtained, that the object of his search has been attained. As a matter of fact, the key is intended simply to lead him by the quickest method to a thorough study of the substance.

The key in the following pages consists of a series of tables[1] in two divisions. The first includes those minerals that have a metallic luster, and a few which might be confused with these. Minerals with a metallic luster are opaque in their thinnest edges. Most of them give a black or dark-colored streak. The second division includes the remaining minerals, i.e., those with a non-metallic luster. These are transparent in very thin splinters and upon their thin edges, and most of them give a colorless or light-colored streak. The sub-divisions are based on color of streak, color in reflected light and hardness.

In testing for hardness, it is important to know that the scratching substance will actually scratch

[1] The names of a few minerals are included in the tables, although the minerals are not described in the text. In these cases, there are, naturally, no reference numbers.

the substance being tested, and also that the latter will not scratch the former. Further, it is likewise important that the scratching substance be clean and fresh. If a cent or a knife blade is being used for scratching, they should be bright; if a mineral, it should not be coated with a tarnish or a weathered layer.

It is convenient to remember that minerals with a hardness of less than 2.5 will leave a mark on paper; those with a hardness of less than 3.5 can be scratched by a cent; those with a hardness of less than 5.5 can be scratched by a good knife blade; and those with a hardness of less than 7 can be scratched by quartz.

It is also to be remembered that the color of a mineral is its color on a fresh fracture and not on a weathered surface.

The tables in this book are intended to serve as a guide to the sections in which the minerals are described. Recourse must be had to the description before the nature of the substance being studied can be established.

A. MINERALS WITH METALLIC LUSTER[1]

STREAK BLACK OR DARK GRAY

Color.	Name.	Hardness.	Ref. No.	Name.	Hardness.	Ref. No.
White or Light Gray	Stibnite	2–2.5	7	Smaltite	5.5	21
	Galena	2.5	9	Arsenopyrite	5.5–6	22
	Cobaltite	5.5	20	Marcasite	6–6.5	15
Brassy Bronze	Bornite	3–3.5	18	Niccolite	5.5	19
	Chalcopyrite	3.5–4	17	Pyrite	5–6.5	14
	Pyrrhotite	3.5–4.5	16	Marcasite	6–6.5	15
Dark Gray or Black	Molybdenite	1–1.5	8	Staurolite	4	93
	Graphite	1–1.5	2	Wolframite	5–5.5	69
	Pyrolusite	1–2	41	Ilmenite	5–6	132
	Wad	1–2.5	MnO_2 +Aq.	Magnetite	5.5–6.5	47
				Franklinite	5.5–6.5	49
	Stibnite	2–2.5	7	Columbite	6–6.5	79
	Galena	2.5	9	Tantalite	6–6.5	80
	Chalcocite	2.5–3	11	Corundum	7–9	37
	Tetrahedrite	3–4	25			
	Uraninite	3–5.5	84			
Blue	Covellite	1.5–2	12			
Brown	Wad	1–3	MnO_2 +Aq.			

STREAK RED

Dark Gray or Black	Wad	1–3	MnO_2 +Aq.	Cuprite	3.5–4	35
	Hematite	2–3	38	Wolframite	5–5.5	69
	Copper	2.5–3	4	Samarskite	5–6	81
	Pyrargyrite	2.5–3	24	Franklinite	5.5–6.5	49
	Tetrahedrite	3–4	25	Hematite	6–6.5	38
				Columbite	6–6.5	79
Brown	Wad	1–3	MnO_2 +Aq.	Wolframite	5–5.5	69
	Hematite	2–3	38			
Red	Hematite	2–3	38	Copper	2.5–3	4
	Cinnabar	2–2.5	13	Gold	2.5–3	6
	Proustite	2.5	23	Hematite	3–6	38
	Pyrargyrite	2.5–3	24			

[1]Where no reference number is given, the mineral is not described in the text. Its composition is indicated for the purpose of identification.

A. MINERALS WITH METALLIC LUSTER—*Continued*

STREAK YELLOW

Color.	Name.	Hardness.	Ref. No.	Name.	Hardness.	Ref. No.
Dark Gray or Black	Siderite	3.5–4	53	Samarskite	5–6	81
	Sphalerite	3.5–4	10	Brookite	5.5–6	39
	Limonite	5–5.5	45	Rutile	6–7	39
	Huebnerite	5–5.5	69	Cassiterite	6–7	40
	Hornblende	5–6	116			
Brown	Limonite	1–5.5	45	Limonite	5–5.5	45
	Sphalerite	3.5–4	10	Brookite	5.5–6	39
	Zincite	4–4.5	36	Rutile	6–7	39
	Huebnerite	4.5–5.5	69	Cassiterite	6–7	40
Yellow	Limonite	1.5–5	45	Huebnerite	4.5–5	69
	Gold	2.5–3	6	Limonite	5–5.5	45
	Sphalerite	3.5–4	10	Cassiterite	6–7	40
Red	Sphalerite	3.5–4	10	Brookite	5.5–6	39
	Zincite	4–4.5	36	Rutile	6–7	39

STREAK BROWN

Dark Gray or Black	Wad	1–3	MnO_2 +Aq.	Samarskite	5–6	81
	Hematite	2–3	38	Chromite	5.5	48
	Tetrahedrite	3–4	25	Brookite	5.5–6	39
	Uraninite	3.5–5	84	Franklinite	5.5–6.5	49
	Siderite	3.5–4	53	Hematite	6–6.5	38
	Sphalerite	3.5–4	10	Columbite	6–6.5	79
	Cuprite	3.5–4	35	Tantalite	6–6.5	80
	Limonite	4.5–5.5	45	Rutile	6–7	39
	Huebnerite	5–5.5	69	Cassiterite	6–7	40
	Wolframite	5–6	69	Spinel	7.5–8	46
	Hornblende	5–6	116	Corundum	7–9	37
	Ilmenite	5–6	132			
Brown	Wad	1–3	MnO_2 +Aq.	Ilmenite	5–6	132
	Hematite	1–6	38	Brookite	5.5–6	39
	Limonite	1–5.5	45	Franklinite	5.5–6.5	49
	Siderite	3.5–4	53	Columbite	6–6.5	79
	Sphalerite	3.5–4	10	Rutile	6–7	39
	Uraninite	3.5–5	84	Cassiterite	6–7	40
	Huebnerite	4.5–5.5	69	Spinel	7.5–8	46
	Wolframite	5–6	69			

A. MINERALS WITH METALLIC LUSTER—*Continued*

STREAK BROWN—*Continued*

Color.	Name.	Hardness.	Ref. No.	Name.	Hardness.	Ref. No.
Yellow	Limonite	1–5.5	45	Huebnerite	4.5–5.5	69
	Siderite	3.5–4	53	Cassiterite	6–7	40
	Sphalerite	3.5–4	10	Spinel	7.5–8	46
Red	Cinnabar	2–2.5	13	Rutile	6–7	39
	Cuprite	3.5–4	35			

STREAK GREEN

Green	Uraninite	3–5.5	84	Augite	5–6	111
	Hornblende	5–6	116	Spinel	7.5–8	46
Brown or Red	Uraninite	3–5.5	84	Huebnerite	4.5–5.5	69

STREAK GRAY

Silver-white	Silver	2.5–3	5	Platinum	4–5	Pt
	Antimony	3–4	Sb			
Dark Gray or Black	Molybdenite	1–1.5	8	Hornblende	5–6	116
	Graphite	1–2	2	Augite	5–6	111
	Silver	2.5–3	5	Hypersthene	5–6	110
	Biotite	2.5–3	95	Brookite	5.5–6	39
	Sphalerite	3.5–4	10	Rutile	6–7	39
	Titanite	5–5.5	131	Spinel	6–7	46
	Huebnerite	5–5.5	69			
Brown	Huebnerite	5–5.5	69	Rutile	6–7	39
	Brookite	5.5–6	39	Cassiterite	6–7	40

STREAK WHITE

Silver-white	Silver	2.5–3	5	Antimony	3–4	Sb
Dark Gray or Black	Biotite	2.5–3	95	Hypersthene	5–6	110
	Silver	2.5–3	5	Cassiterite	6–7	40
	Titanite	5–5.5	131	Garnet	6.5–7	88
	Hornblende	5–6	116	Tourmaline	7–7.5	108
	Augite	5–6	111	Spinel	7.5–8	46
Brown	Cassiterite	6–7	40			

B. MINERALS WITH NON-METALLIC LUSTER

STREAK DARK GRAY OR BLACK

Color.	Name.	Hardness.	Ref. No.	Name.	Hardness.	Ref. No.
Dark Gray or Black	Graphite.....	1–2	2	Psilomelane [1].	5–6	Mn-Ba-K
	Wad.....	1–3	MnO_2 +Aq.			
	Wolframite...	5–5.5	69	Corundum...	7–9	37
Brown	Wad.....	1–3	MnO_2 +Aq.			

STREAK BROWN

Dark Gray or Black	Wad.....	1–3	MnO_2 +Aq.	Hornblende..	5–6	116
	Uraninite....	3–5.5	84	Psilomelane..	5–6	Mn-Ba-K
	Siderite.....	3.5–4	53			
	Sphalerite....	3.5–4	10	Chromite....	5–6	48
	Cuprite.....	3.5–4	35	Brookite.....	5.5–6	39
	Goethite.....	4.5–5.5	45	Rutile.....	6–7	39
	Ferberite....	4.5–5	69	Cassiterite...	6–7	40
	Wolframite...	5–5.5	69	Spinel.....	7.5–8	46
Brown	Wad.....	1–3	MnO_2 +Aq.	Goethite.....	4.5–5	45
	Hematite.....	1–3	38	Huebnerite...	4.5–5	69
	Limonite.....	1–3	45	Wolframite...	5–5.5	69
	Bauxite.....	1–3	44	Hornblende..	5–6	116
	Cinnabar....	2–2.5	13	Brookite.....	5.5–6	39
	Chrysocolla..	2–4	121	Rutile.....	6–7	39
	Uraninite....	3–5.5	84	Cassiterite...	6–7	40
	Siderite.....	3.5–4	53	Spinel.....	7.5–8	46
	Sphalerite....	3.5–4	10			
Red	Hematite....	1–3	38	Huebnerite...	4.5–5	69
	Cinnabar....	2–2.5	13	Wolframite...	5–5.5	69
	Hematite....	3–6	38	Rutile.....	6–6.5	39
	Cuprite.....	3.5–4	35	Cassiterite...	6–7	40
	Sphalerite....	3.5–4	10			
Yellow	Bauxite.....	1–3	44	Goethite.....	4–5.5	45
	Limonite.....	1–3	45			

[1] The composition of psilomelane is doubtful. The mineral contains the three elements indicated.

B. MINERALS WITH NON-METALLIC LUSTER—*Continued*

STREAK RED

Color.	Name.	Hardness.	Ref. No.	Name.	Hardness.	Ref. No.
Dark Gray or Black	Hematite	1–3	38	Cuprite	3.5–4	35
Brown	Cinnabar	2–2.5	13	Hematite	3–6	38
Red	Bauxite	1–3	44	Pyrargyrite	2.5–3	24
	Hematite	1–3	38	Crocoite	2.5–3	71
	Erythrite	1.5–2	77	Zincite	4–4.5	36
	Cinnabar	2–2.5	13	Wolframite	5–5.5	69
	Proustite	2–5	23			
Yellow	Hematite	3–6	38			

STREAK YELLOW

Dark Gray or Black	Siderite	3.5–4	53	Rutile	6–7	39
	Huebnerite	4.5–5.5	69	Cassiterite	6–7	40
	Brookite	5.5–6	39			
Brown	Wad	1–3	MnO_2 +Aq.	Huebnerite	4.5–5.5	69
	Limonite	1–3	45	Brookite	5.5–6	39
	Bauxite	1–3	44	Rutile	6–6.5	39
	Siderite	3.5–4	53	Cassiterite	6–7	40
	Sphalerite	3.5–4	10			
Red	Bauxite	1–3	44	Zincite	4–4.5	36
	Wulfenite	3	70	Huebnerite	4.5–5.5	69
	Vanadinite	3	75	Rutile	6–6.5	39
	Sphalerite	3.5–4	10	Cassiterite	6–7	40
Yellow	Bauxite	1–3	44	Vanadinite	3	75
	Limonite	1–3	45	Pyromorphite	3.5–4	73
	Sulphur	1.5–2	3	Sphalerite	3.5–4	10
	Carnotite	2–3	83	Zincite	4–4.5	36
	Wulfenite	3	70			

STREAK ORANGE

Red	Crocoite	2–5	71	Zincite	4–4.5	36

B. MINERALS WITH NON-METALLIC LUSTER—*Continued*

STREAK GREEN

Color.	Name.	Hardness.	Ref. No.	Name.	Hardness.	Ref. No.
Dark Gray or Black	Uraninite...	3–3.5	84	Spinel.....	7.5–8	46
	Augite.....	5–6	111			
Green	Glauconite..	1–2	*	Pyromorphite	3.5–4	73
	Chlorites....	1–2.5	100	Hornblende..	5–6	116
	Chrysocolla.	2–3	121	Augite.....	5–6	111
	Atacamite..	3–3.5	$Cu_2(OH)_3Cl$	Turquois.....	6	78
	Malachite...	3.5–4	60	Chloritoid....	6–7	99

STREAK BLUE

Blue	Vivianite...	1.5–2	$Fe_3(PO_4)_2 \cdot 8H_2O$	Azurite.....	3.5–4	61
	Chrysocolla.	2–3	121	Glaucophane.	6–6.5	117
Green	Crocidolite .	4	$NaFe(Fe,Mg)(SiO_3)_2$			

STREAK WHITE

Dark Gray or Black	Gypsum.....	1.5–2	67	Yttrotantalite	5–5.5	82
	Halite.....	2–2.5	27	Hornblende..	5–6	116
	Apatite.....	2–5	72	Augite.....	5–6	111
	Biotite.....	2–5	95	Hypersthene.	5–6	110
	Calcite.....	3	50	Octahedrite..	5.5–6	39
	Anhydrite....	3–3.5	62	Brookite.....	5.5–6	39
	Cerussite....	3–3.5	59	Labradorite..	6–6.5	120
	Serpentine...	3–4	104	Epidote.....	6–7	92
	Wavellite....	3.5–4	76	Chloritoid....	6–7	99
	Ankerite.....	3.5–4	$Ca(Mg,Fe)(CO_3)_2$	Rutile.....	6–7	39
	Dolomite....	3.5–4	51	Cassiterite...	6–7	40
	Sphalerite....	3.5–4	10	Garnet.....	6.5–7.5	88
	Magnesite ..	3.5–5	52	Quartz.....	7	34
	Fluorite....	4	29	Tourmaline ..	7–7.5	108
	Huebnerite..	4.5–5.5	69	Staurolite....	7–7.5	93
	Titanite....	5–5.5	131	Spinel.....	7.5–8	46
	Glaucophane	5–5.5	117	Diamond...	10	1

* Hydrous silicate of K and Fe.

B. MINERALS WITH NON-METALLIC LUSTER—*Continued*

STREAK WHITE—*Continued*

Color.	Name.	Hardness.	Ref. No.	Name.	Hardness.	No. Ref.
	Cerargyrite	1–1.5	26	Chabazite	4–5	128
	Tripolite	1–2.5	SiO_2	Harmotome	4–5	124
	Kaolinite	1–2.5	106	Apatite	4.5–5	72
	Gypsum	1.5–2	67	Calamine	4.5–5	107
	Halite	2–2.5	27	Huebnerite	4.5–5	69
	Muscovite	2–3	96	Smithsonite	5	54
	Phlogopite	2–3	95	Titanite	5–5.5	131
	Apatite	2–3	72	Nephelite	5–6	94
	Biotite	2.5–3	95	Enstatite	5–6	110
	Chrysotile	2.5–3	104	Bronzite	5–6	110
	Barite	2.5–3.5	63	Hypersthene	5–6	110
	Vanadinite	3	75	Hornblende	5–6	116
	Wulfenite	3	70	Augite	5–6	111
	Calcite	3	50	Willemite	5–6	86
	Anglesite	3–3.5	65	Troostite	5–6	87
Brown	Serpentine	3–4	104	Opal	5.5–6	42
	Stilbite	3–4	125	Octahedrite	5.5–6	39
	Laumontite	3–4	126	Brookite	5.5–6	39
	Apatite	3.5	72	Epidote	6–7	92
	Dolomite	3.5–4	51	Rutile	6–7	39
	Sphalerite	3.5–4	10	Cassiterite	6–7	40
	Wavellite	3.5–4	76	Vesuvianite	6.5	109
	Aragonite	3.5–4	56	Olivine	6.5–7	85
	Strontianite	3.5–4	57	Garnet	6.5–7.5	88
	Siderite	3.5–4	53	Quartz	7	34
	Pyromorphite	3.5–4	73	Tourmaline	7–7.5	108
	Mimetite	3.5–4	74	Staurolite	7–7.5	93
	Rhodochrosite	3.5–4	55	Zircon	7.5	89
	Magnesite	3.5–5	52	Spinel	7.5–8	46
	Fluorite	4	29	Corundum	9	37
	Clintonite*	4–5	99	Diamond	10	1
	Cerargyrite	1–1.5	26	Wulfenite	3	70
	Glauconite	1–2	†	Anglesite	3–3.5	65
	Kaolinite	1–2.5	106	Stilbite	3–4	125
	Talc	1–2.5	105	Serpentine	3–4	104
	Chlorites	1–2.5	100	Wavellite	3.5–4	76
	Halite	2–2.5	27	Aragonite	3.5–4	56
Green	Brucite	2–2.5	43	Strontianite	3.5–4	57
	Actinolite	2–3	114	Pyromorphite	3.5–4	73
	Chrysocolla	2–3	121	Rhodochrosite	3.5–4.5	55
	Chrysotile	2.5–3	104	Fluorite	4	29
	Phlogopite	2.5–3	95	Scheelite	4–5	68
	Biotite	2.5–3	95	Apatite	4.5–5	72
	Barite	2.5–3	63	Calamine	4.5–5	107

*A calcium-bearing brittle mica, † Hydrous silicate of K and Fe.

B. MINERALS WITH NON-METALLIC LUSTER—*Continued*

STREAK WHITE—*Continued*

Color.	Name.	Hardness.	Ref. No.	Name.	Hardness.	Ref. No.
Green	Smithsonite.	5	54	Microcline.	6–6.5	119
	Titanite....	5–5.5	131	Epidote.....	6–7	92
	Hornblende.	5–6	116	Chloritoid...	6–7	99
	Augite.....	5–6	111	Vesuvianite	6.5	109
	Hypersthene	5–6	110	Olivine.....	6.5–7	85
	Nephelite...	5–6	94	Garnet....	6.5–7.5	88
	Actinolite...	5–6	114	Quartz	7	34
	Enstatite...	5–6	110	Tourmaline	7–7.5	108
	Bronzite....	5–6	170	Spinel.....	7.5–8	46
	Willemite...	5–6	86	Beryl.....	7.5–8	103
	Opal.....	5–6	42	Topaz.....	8	91
	Turquoise...	6	78	Corundum.	9	37
	Labradorite.	6–6.5	120			
Pink	Laumontite.	1–1–2	126	Fowlerite..	5–6	$(Mn,Zn)SiO_3$
	Gypsum....	1.5–2	67	Willemite..	5–6	86
	Lepidolite...	2–4	98	Rhodonite.	5.5–6.5	$MnSiO_3$
	Calcite.....	3	50	Tephroite..	6	Mn_2SiO_4
	Laumontite.	3–4	126	Orthoclase.	6–6.5	118
	Dolomite...	3.5–4	51	Epidote....	6–7	92
	Alunite.....	3.5–4	66	Andalusite.	6–7.5	90
	Rhodochrosite	3.5–4.5	55	Garnet....	6.5–7	88
				Tourmaline	7–7.5	108
	Fluorite....	4	29	Topaz.....	8	91
	Apophyllite.	4.5–5	122	Spinel.....	8	46
	Tremolite...	5–6	113	Corundum.	9	37
Yellow	Cerargyrite..	1–1.5	26	Stilbite....	3–4	125
	Carnallite...	1–2	*	Laumontite	3–4	126
	Kaolinite ...	1–2.5	106	Serpentine.	3–4	104
	Talc.....	1–2.5	105	Wavellite..	3.5–4	76
	Gypsum....	1.5–2	67	Dolomite..	3.5–4	51
	Sulphur.....	1.5–2.5	3	Aragonite..	3.5–4	56
	Sylvite	2–2.5	28	Strontianite	3.5–4	57
	Halite.....	2–2.5	27	Sphalerite..	3.5–4	10
	Muscovite...	2–3	96	Pyromorphite....	3.5–4	73
	Phlogopite..	2–3	95			
	Chrysotile ..	2.5–3	104	Mimetite..	3.5–4	74
	Barite.....	2.5–3.5	63	Rhodochrosite	3.5–4.5	55
	Calcite.....	3	50			
	Wulfenite...	3	70	Magnesite.	3.5–5	52
	Vanadinite..	3	75	Fluorite...	3.5–5	29
	Celestite....	3–3.5	64	Chabazite..	4–5	128
	Anglesite...	3–3.5	65	Harmotome	4–5	124
	Cerussite..	3–3.5	59	Phillipsite..	4–5	123

* $KMgCl_3 \cdot 6H_2O$

B. MINERALS WITH NON-METALLIC LUSTER—*Continued*

STREAK WHITE—*Continued*

Color.	Name	Hardness.	Ref. No.	Name.	Hardness.	Ref. No.
Yellow	Scheelite	4.5	68	Orthoclase	6–6.5	118
	Apatite	4.5–5	72	Epidote	6–7	92
	Calamine	4.5–5	107	Vesuvianite	6.5	109
	Huebnerite	4.5–5	69	Garnet	6.5–7.5	88
	Smithsonite	5	54	Quartz	7	34
	Natrolite	5–5.5	129	Tourmaline	7–7.5	108
	Titanite	5–5.5	131	Zircon	7.5	89
	Nephelite	5–6	94	Beryl	7–8	103
	Enstatite	5–6	110	Spinel	7.5–8	46
	Willemite	5–6	86	Topaz	8	91
	Opal	5.5–6	42	Corundum	9	37
Red	Laumontite	1–3	126	Scheelite	4.5–5	68
	Kaolinite	1–2.5	106	Apophyllite	4.5–5	122
	Talc	1–2.5	105	Apatite	4.5–5	72
	Gypsum	1.5–2	67	Huebnerite	4.5–5.5	69
	Sylvite	2–2.5	28	Analcite	5–5.5	130
	Halite	2–2.5	27	Natrolite	5–5.5	129
	Phlogopite	2.5–3	95	Titanite	5–5.5	131
	Calcite	3	50	Nephelite	5–6	94
	Wulfenite	3	70	Willemite	5–6	86
	Vanadinite	3	75	Opal	5–6	42
	Anhydrite	3–3.5	62	Orthoclase	6–6.5	118
	Celestite	3–3.5	64	Epidote	6–7	92
	Barite	3–3.5	63	Rutile	6–7	39
	Stilbite	3–4	125	Cassiterite	6–7	40
	Laumontite	3–4	126	Olivine	6.5–7	85
	Serpentine	3–4	104	Garnet	6.5–7.5	88
	Dolomite	3.5–4	51	Quartz	7	34
	Aragonite	3.5–4	56	Tourmaline	7–7.5	108
	Ankerite	3.5–4	$Ca(Mg,Fe)(CO_3)_2$	Zircon	7.5	89
	Sphalerite	3.5–4	10	Spinel	7.5–8	46
	Rhodochrosite	3.5–4	55	Topaz	8	91
	Chabazite	4–5	128	Corundum	9	37
	Harmotome	4–5	124			
Blue	Kaolin	1–2.5	106	Anglesite	3–3.5	65
	Sylvite	2–2.5	28	Aragonite	3.5–4	56
	Halite	2–2.5	27	Wavellite	3.5–4	76
	Brucite	2–2.5	43	Fluorite	4	29
	Chrysocolla	2–4	121	Apatite	4.5–5	72
	Barite	2.5–3.5	63	Calamine	4.5–5	107
	Calcite	3	50	Smithsonite	5	54
	Celestite	3–3.5	64	Nephelite	5–6	94

B. MINERALS WITH NON-METALLIC LUSTER—*Continued*.

STREAK WHITE—*Continued*

Color.	Name.	Hardness.	Ref. No	Name	Hardness.	Ref. No.
Blue	Opal	5.5–6	42	Tourmaline	7–7.5	108
	Turquoise	6	78	Beryl	7–8	103
	Glaucophane	6–6.5	117	Spinel	7.5–8	46
	Vesuvianite	6–7	109	Topaz	8	91
	Quartz	7	34	Corundum	9	37
Purple	Halite	2–2.5	27	Quartz	7	34
	Calcite	3	50	Topaz	8	91
	Fluorite	4	29	Spinel	8	46
	Apatite	4.5–5	72	Corundum	9	37
	Tremolite	5–6	113			
Bronze	Phlogopite	2.5–3	95			
Orange	Vanadinite	3	75	Spinel	8	46
White or Light Gray	Cerargyrite	1–1.5	26	Strontianite	3.5–4	57
	Calcite	1–2.5	50	Siderite	3.5–4	53
	Talc	1–2.5	105	Ankerite	3.5–4	*
	Brucite	1–2.5	43	Alunite	3.5–4	66
	Bauxite	1–3	44	Pyromorphite	3.5–4	73
	Niter	1.5–2	30	Mimetite	3.5–4	74
	Soda-niter	1.5–2	31	Rhodochrosite	3.5–4.5	55
	Gyspum	1.5–2	67	Magnesite	3.5–4.5	52
	Sylvite	2–2.5	28	Fluorite	4	29
	Halite	2–2.5	27	Wollastonite	4	$CaSiO_3$
	Muscovite	2–3	96	Colemanite	4–5	33
	Paragonite	2–3	97	Chabazite	4–5	128
	Lepidolite	2–4	98	Apophyllite	4–5	122
	Apatite	2–5	72	Harmotome	4–5	124
	Chrysotile	2.5–3	104	Phillipsite	4–5	123
	Barite	2.5–3	63	Scheelite	4–5	68
	Calcite	3	50	Kyanite	4–5	102
	Wulfenite	3	70	Apatite	4.5–5	72
	Celestite	3–3.5	64	Calamine	4.5–5	107
	Anglesite	3–3.5	65	Smithsonite	5	54
	Cerussite	3–3.5	59	Analcite	5–5.5	130
	Stilbite	3–4	125	Natrolite	5–5.5	129
	Laumontite	3–4	126	Scolecite	5–5.5	127
	Andalusite	3–6	90	Nephelite	5–6	94
	Wavellite	3.5–4	76	Tremolite	5–6	113
	Dolomite	3.5–4	51	Enstatite	5–6	110
	Witherite	3.5–4	58	Asbestus	5–6	115
	Aragonite	3.5–4	56	Willemite	5–6	86

* $Ca(Mg,Fe)(CO_3)_2$.

B. MINERALS WITH NON-METALLIC LUSTER—*Continued*

STREAK WHITE—*Continued*

Color.	Name.	Hardness.	Ref. No.	Name.	Hardness.	Ref. No.
White or Light Gray	Opal	5.5–6	42	Tourmaline	7–7.5	108
	Leucite	5.5–6	101	Zircon	7.5	89
	Orthoclase	6–6.5	118	Beryl	7–8	103
	Microcline	6–6.5	119	Topaz	8	91
	Plagioclase	6–6.5	120	Corundum	9	37
	Garnet	6.5–7.5	88	Diamond	10	1
	Quartz	7	34			

VI

LIST OF MINERALS ARRANGED ACCORDING TO THEIR IMPORTANT CONSTITUENTS

ALUMINIUM

Albite (120)
Alunite (66)
Andalusite (90)
Anorthite (120)
Augite (111)
Bauxite (44)
Beryl (103)
Brittle micas (99)
Corundum (37)
Cyanite (102)
Garnet (88)
Glaucophane (117)
Hornblende (116)
Kaolinite (106)
Kyanite (102)
Leucite (101)
Micas (95–100)
Microcline (119)
Nephelite (94)
Orthoclase (118)
Spinel (46)
Spodumene (112)
Staurolite (93)
Topaz (91)
Tourmaline (108)
Turquoise (78)
Vesuvianite (109)
Wavellite (76)
Zeolites (123–130)

ANTIMONY

Pyrargyrite (24)
Stibnite (7)
Tetrahedrite (25)

ARSENIC

Arsenopyrite (22)
Cobaltite (20)
Erythrite (77)
Mimetite (74)
Niccolite (19)
Proustite (23)
Smaltite (21)
Tetrahedrite (25)

BARIUM

Barite (63)
Harmotome (124)
Psilomelane
Witherite (58)

BERYLLIUM

Beryl (103)

BORON

Borax (32)
Colemanite (33)
Tourmaline (108)

CALCIUM

Actinolite (114)
Andradite (88)
Anhydrite (62)
Anorthite (120)
Apatite (72)
Apophyllite (122)
Aragonite (56)
Asbestus (115)
Augite (111)
Calcite (50)
Carnotite (83)
Chabazite (128)
Colemanite (33)
Dolomite (51)
Epidote (92)
Fluorite (29)
Grossularite (88)
Gypsum (67)
Heulandite
Hornblende (116)
Laumontite (126)
Phillipsite (123)
Scheelite (68)
Scolecite (127)
Stilbite (125)
Titanite (131)
Tremolite (113)
Uvarowite (88)
Vesuvianite (109)

CARBON

Carbonates (50–61)
Diamond (1)
Graphite (2)

CHLORINE

Apatite (72)
Atacamite (60)
Cerargyrite (26)
Halite (27)
Mimetite (74)
Pyromorphite (73)
Sylvite (28)
Vanadinite (75)

CHROMIUM

Chromite (48)
Crocoite (71)
Uvarowite (88)

COBALT

Cobaltite (20)
Erythrite (77)
Smaltite (21)

COLUMBIUM

Columbite (79)
Samarskite (81)

COPPER

Atacamite (69)
Azurite (61)
Bornite (18)
Chalcocite (11)
Chalcopyrite (17)
Chrysocolla (121)
Copper (4)
Covellite (12)
Cuprite (35)
Cyprine (109)
Malachite (60)
Tetrahedrite (25)
Turquoise (78)

FLUORINE

Apatite (72)
Fluorite (29)
Lepidolite (98)
Topaz (91)
Vesuvianite (109)

GOLD

IRON

Actinolite (114)
Almandite (88)
Andradite (88)
Arsenopyrite (22)
Augite (111)
Biotite (95)
Bornite (18)
Bronzite (110)
Chalcopyrite (17)
Chromite (48)
Columbite (79)
Fayalite (85)
Franklinite (49)
Garnet (88)
Goethite (45)
Hematite (38)
Ilmenite (132)
Limonite (45)
Magnetite (47)
Marcasite (15)
Olivine (85)
Pyrite (14)
Pyrrhotite (16)
Siderite (53)
Staurolite (93)
Tantalite (80)
Wolframite (69)

LEAD

Anglesite (65)
Cerussite (59)
Crocoite (71)
Galena (9)
Mimetite (74)
Pyromorphite (73)
Vanadinite (75)
Wulfenite (70)

LITHIUM

Lepidolite (98)
Spodumene (112)

MAGNESIUM

Actinolite (114)
Asbestus (115)
Augite (111)
Biotite (95)
Brittle micas (99)
Bronzite (110)
Brucite (43)
Chlorites (100)
Chrysotile (104)
Dolomite (51)
Enstatite (110)
Glaucophane (117)
Hornblende (116)
Hypersthene (110)
Magnesite (52)
Olivine (85)
Phlogopite (95)
Pyrope (88)
Serpentine (104)
Spinel (46)
Steatite (105)
Tremolite (113)

MANGANESE

Columbite (79)
Franklinite (49)
Psilomelane
Pyrolusite (41)
Rhodochrosite (55)
Rhodonite ($MnSiO_3$)
Spessartite (88)
Tantalite (80)
Troostite (87)
Wolframite (69)

MERCURY

Cinnabar (13)

MOLYBDENUM

Molybdenite (8)
Wulfenite (70)

NICKEL

Niccolite (19)

NITROGEN

Nitrates (30–31)

PHOSPHORUS

Apatite (72)
Pyromorphite (73)
Turquoise (78)
Wavellite (76)

POTASSIUM

Alunite 66)
Apophyllite (122)
Biotite (95)
Carnotite (83)
Harmotome (124)
Lepidolite (98)
Leucite (101)
Microcline (119)
Muscovite (96)
Niter (30)
Orthoclase (118)
Phillipsite (123)
Phlogopite (95)
Psilomelane
Sylvite (28)

SILICON

Opal (42)
Quartz (34)
Silicates (85–132)

SILVER

Argentite (Ag_2S)
Cerargyrite (26)
Proustite (23)
Pyrargyrite (24)
Silver (5)

SODIUM

Albite (120)
Analcite (130)
Borax (32)
Chabazite (128)
Glaucophane (117)
Halite (27)
Natrolite (129)
Nephelite (94)
Soda-niter (31)
Sphene (131)
Stilbite (125)

STRONTIUM

Celestite (64)
Strontianite (57)

SULPHUR

Arsenopyrite (22)
Cobaltite (20)
Marcasite (15)
Pyrite (14)
Pyrrhotite (16)
Sulph-antimonites (23–25)
Sulph-arsenites (23–25)
Sulphates (62–67)
Sulphides (7–18)
Sulphur (3)

TANTALUM

Tantalite (80)

TIN

Cassiterite (40)

TITANIUM

Brookite (39)
Ilmenite (132)
Octahedrite (39)
Rutile (39)
Titanite (131)

TUNGSTEN

Scheelite (68)
Wolframite (69)

URANIUM

Carnotite (83)
Uraninite (84)

VANADIUM

Carnotite (83)
Vanadinite (75)

ZINC

Calamine (107)
Franklinite (49)
Smithsonite (54)
Sphalerite (10)
Troostite (87)
Willemite (86)
Zincite (36)

ZIRCONIUM

Zircon (89)

YIELDING WATER IN CLOSED TUBE

Alunite (63)
Apophyllite (122)
Atacamite (60)
Azurite (61)
Bauxite (44)
Biotite (95)
Borax (32)
Brittle micas (99)
Brucite (43)
Calamine (107)
Chlorites (100)
Chrysocolla (121)
Chrysotile (104)
Colemanite (33)
Epidote (92)
Erythrite (77)
Goethite (45)
Gypsum (67)
Kaolin (106)
Lepidolite (98)
Limonite (45)
Malachite (60)
Muscovite (96)
Opal (42)
Phlogopite (95)
Psilomelane
Serpentine (104)
Staurolite (93)
Steatite (105)
Tourmaline (108)
Topaz (91)
Turquoise (78)
Vesuvianite (109)
Wavellite (76)
Zeolites (123–130)

COLLECTIONS

Suites of specimens to illustrate the minerals described in this volume may be obtained from Ward's Natural Science Establishment, Rochester, N. Y.

Collection No. 1: 128 specimens, including all but four of the minerals described, each in tray, 1⅛×1½ in., in two pine boxes..... $7.50
Collection No. 2: 132 specimens, averaging 1½×2½ in., in trays..... 25.00
Collection No. 3: 132 specimens, averaging 3×4 in., in trays..... 60.00
Collection No. 4: 180 specimens, all minerals described and varieties, averaging 1½×2½ in., in trays..... 35.00
Collection No. 5: Same, averaging 3×4 in., in trays..... 100.00

II

ROCKS

I

SYNOPSIS OF A CLASSIFICATION OF ROCKS

A *rock* is a structural unit of the earth's crust.

It may consist of a single mineral, a mixture of minerals, a mixture of organic compounds, or a mixture of minerals and organic material. Its essential feature is the fact that it is an integral portion of the crust.

On the other hand, a mineral is a chemical compound which possesses definite properties because of its chemical composition. The properties of a rock depend only partly upon its chemical composition. They are determined also in part by its method of occurrence and its origin. Thus, granite possesses properties that are due in part to the fact that it is composed of quartz, orthoclase and, perhaps, biotite, but also to the fact that it is coarse-grained and that it occurs in large structureless masses, which are the result of its manner of origin. The characters of quartz, however, are due to the fact that it is composed of a certain number of silicon and oxygen atoms, arranged in a certain definite manner in its molecules.

Stone is an engineering or architectural term and has no significance except as indicating a certain kind of structural material.

Rocks may be classified from the point of view of composition, of structure, or of genesis.

A *classification* according to genesis demands that the origin of the rock be known, which, of course,

in many cases cannot be discovered. A genetic classification is the only logical one, but it can come only after all the facts concerning the things classified are known.

Under the present condition of knowledge concerning rock masses, a genetic classification is impossible, except along very broad lines. For our purpose, rocks will be considered as bodies to be grouped according to features they possess as materials.

In this meaning, the following classification is proposed: (*A*) *crystalline rocks*; (*B*) *fragmental rocks*. The former are composed of material which originated in its present position, and which, therefore, is principally crystalline, e.g., granite; the second class includes those rocks formed of material a large part of which originated elsewhere, e.g., sandstone.

A. CRYSTALLINE ROCKS

Crystalline rocks are composed of minerals which crystallized from (1) aqueous or (2) molten solutions, or of minerals and glass, or of glass alone, formed by the quick cooling of a magma. Another (3) group consists of crystalline particles which have been formed by the reactions of gases and solutions upon the pre-existing components of certain rocks, or by the reactions of these components with one another.

1. Aqueous solutions yield solid minerals upon evaporation or cooling; and the minerals normally separate at the bottom of the solutions as sediments.

Because thus separated, they usually occur in layers or strata, and because a mixed solution generally precipitates a single substance until most of it has been removed from the solution, rocks of this kind usually

consist of an aggregate of crystalline particles of a single mineral. The aggregate is coarse-grained if precipitation is slow, and fine-grained if rapid.

2. Molten solutions solidify upon cooling. Under certain conditions, a given mineral may separate before others (see Fig. 96); under other conditions, several minerals may separate simultaneously (see Fig. 95); under still other conditions, when the cooling is so rapid that crystallization has not had time to take place, the molten mass or magma may solidify as a glass (see Fig. 94).

3. Rocks composed of minerals of any kind, or of particles of organic material, may be acted upon by gases or solutions which may attack the components and produce new materials. Or pressure may crush the rock, breaking its components into tiny particles, which, under the influence of the pressure and the high temperature produced by the crushing, may force themselves into new compounds, especially in the presence of moisture and gases.

Thus, the crystalline rocks may be subdivided into: (1) *chemical sediments;* (2) *igneous rocks;* (3) *metamorphic rocks.*

The structure, i.e., the arrangement of the constituents of each class, is characteristic. The components of the chemical sediments are arranged in layers, i.e., they are *stratified,* like fragmental sedimentary rocks (see Fig. 102). Those of many of the metamorphic rocks are flattened and arranged with their longer axes approximately parallel, or at least, in the same plane, i.e., the rocks are *schistose* (see Fig. 100). The igneous rocks have no definite arrangement of components. They are said to be *massive.*

With respect to structure crystalline rocks are: (1) Stratified; (2) massive; (3) schistose.

The stratified crystalline rocks are composed essentially of crystalline particles of a single mineral, such as might be thrown down from solution by cooling,

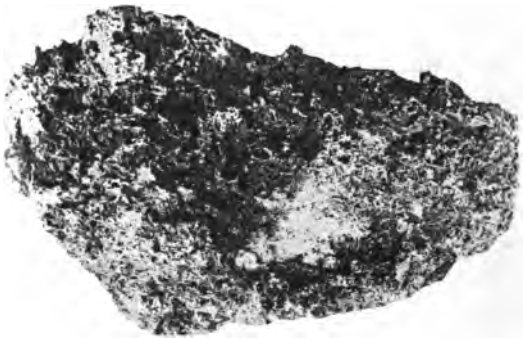


FIG. 93.—Mass of Travertine (½ nat. size).

evaporation, reactions or the life processes of animals or plants. The most important are:

(*a*) *Ice*, H_2O.

(*b*) *Rocksalt*, NaCl (halite).

(*c*) *Chert*, SiO_2 plus Aq. (chalcedony, opal, etc).

1. *Siliceous sinter*, composed of the tests of minute animals and plants.

(*d*) *Gypsum*, $CaSO_4$.

(*e*) *Limestone*, $CaCO_3$ or $(Ca \cdot Mg)CO_3$ (calcite or dolomite).

1. *Oölite*, composed of concretionary grains (Fig. 28).
2. *Stalactite* (Mexican onyx), pendants of radiating fibers.
3. *Travertine*.—Porous, composed of little tubes (Fig. 93).

(*f*) *Limonite*, $Fe_4O_3(OH)_6$, or *Hematite*, Fe_2O_3.

1. *Bog iron ore.*—Porous, composed of little tubes, nodules, etc., of limonite, and containing often remains of plants.
2. *Ferruginous oölite*, composed of concretionary grains of limonite or hematite.

FIG. 94.—Glassy Texture. Obsidian.

The massive rocks are the result of the cooling of a molten magma. According to the conditions under which the cooling occurred, i.e., whether under great or slight pressure, whether rapidly or slowly, etc., the solid mass may be composed of particles of the same or of different sizes and shapes, of materials in the same or different states, etc. The result of these variations is known as *texture*. The important textures are:

Glassy or *amorphous* (Fig. 94), when the rock is composed entirely of glass. The rock is commonly known as an *obsidian* if the glass is fresh and shiny; *pitchstone* if decomposed and dull, irrespective of composition.

Felsitic or *aphanitic*, when the rock material is not glassy, but is so fine-grained that the individual components cannot be distinguished.

FIG. 95.—Granular Texture. Granite.

Granitoid or *granular* (Fig. 95), when the constituents are equidimensional grains, without crystal form.

FIG. 96.—Porphyritic Texture. Feldspar phenocryst in granular groundmass.

Porphyritic (Figs. 96 and 97), when some of the components are larger and more conspicuous (phenocrysts) than those of the aggregate (groundmass) in which they lie. The groundmass may be glassy or

granular. When the phenocrysts are quartz the rock is sometimes called *quartz-porphyry*. Its composition is usually that of a rhyolite (p. 197).

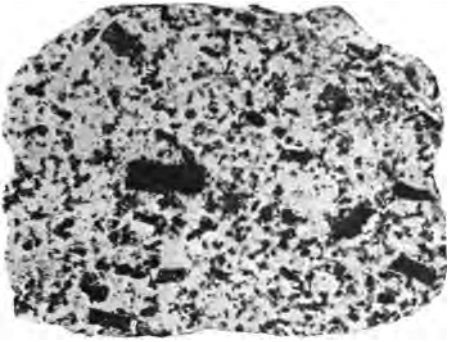


FIG. 97.—Amphibole Phenocrysts in Andesite.

Vesicular (Fig. 98), when the mass of the rock contains pores or cavities which were made by escaping

FIG. 98.—Vesicular Texture. Basalt.

steam or other vapor. When the pores are numerous and very small the rock is known as *pumice*.

Amygdaloidal (Fig. 99), when the pores of a vesicular rock are filled with mineral matter of a different kind from that composing the main mass of the rock.

Fragmental, when the rock's components consist largely of fragments of minerals or particles of glass.

Some massive rocks solidified at great depths, under conditions which resulted in slow, continuous cooling, giving rise to the granular, or granitoid texture, which may be coarse-grained or fine-grained. These are characterized as *plutonic*, because formed at great

FIG. 99.—Amygdaloidal Texture. Basalt.

depths, or *intrusive*, because they cut other rocks. Another class of igneous rocks solidified near the surface, where cooling was comparatively rapid and under low pressures. The resulting textures were glassy, felsitic, porphyritic, vesicular or amygdaloidal. These are said to be *volcanic*, because the best types are among the lavas; or *extrusive* or *effusive*, because most of them flowed out over other rocks. A third, comparatively small class, comprises rocks which are neither plutonic nor volcanic, but are intermediate in

character. They are *dike* fillings. They represent the roots of lava extrusions, or tongues which extend upward from plutonic masses. Their texture is more frequently porphyritic than otherwise.

The separation of the massive rocks into types is based primarily upon their mineral composition, or, in the case of other than granular rocks, partly upon the nature of their phenocrysts and partly upon the chemical composition of their groundmasses.

The principal types of massive rocks are:

Plutonic	Composition	Volcanic
(*a*) *Granite*	Quartz and alk. felds>calc. felds	*Rhyolite*
(*b*) *Syenite*	Alk. felds>calc. felds	*Trachyte*
(*c*) *Monzonite*	Alk. felds=calc. felds	*Latite*
(*d*) *Diorite*	Alk. felds<calc. felds and hornblende	*Andesite*
(*e*) *Gabbro*	Alk. felds<calc. felds and augite	*Basalt*
(*f*) *Peridotite*	Horn., augite, oliv.>felds	*Limburgite*

When so very fine-grained that their mineral components cannot be determined, the light-colored kinds are usually known by the non-committal name *felsite* (p. 194) and dark kinds by the name *basalt.*

The crystalline schists are metamorphic rocks; but not all metamorphic rocks are crystalline schists. The crystalline schists are crystalline rocks which exhibit the schistose structure, i.e., those in which the components are elongated in a common direction (Fig. 100). In some cases the rocks are also foliated —that is, their elongated components are arranged in indefinite layers (Fig. 101), which, however, are not sharply marked as in the case of stratified rocks.

The crystalline schists may originate from igneous or from sedimentary rocks; from crystalline or from fragmental ones. The processes by which they were

formed include mashing, crushing and solution and deposition. Mashing results in the flattening of the

FIG. 100.—Schistose Structure. Gneiss.

original components and crushing results in their fracturing and the movement of their fragments

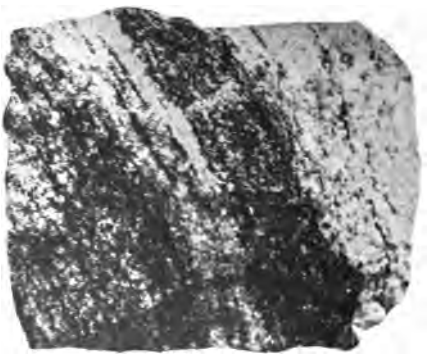


FIG. 101.—Foliated Structure. Gneiss.

along planes inclined to the lines of direction of the greatest pressure. Thus, the original particles are deformed to flat lenses, the parts of which are welded

together by the deposition of material between them. Solution and deposition, without crushing, may also result in schistosity, if the processes occur in rocks which are subjected to differential pressure. Solution of the original components takes place where the greatest pressure is exerted and deposition elsewhere. Consequently, the original grains will become thinner along the directions of greatest pressure and be elongated in directions approximately perpendicular.

The crystalline schists may be divided into the three groups: Gneisses, schists and marbles.

GNEISSES.—The gneisses are comparatively coarse-grained schistose rocks, which may or may not be foliated. Most of them have a mineralogical composition corresponding to that of some massive rocks, and some of these have undoubtedly been derived from massive rocks. Others, having compositions different from those of the igneous rocks, were probably derived from fragmental rocks. Their names suggest their origin.

(*a*) *Granite-gneiss*, with the composition of granite.
(*b*) *Syenite-gneiss*, with the composition of syenite.
(*c*) *Diorite-gneiss*, with the composition of diorite.
(*d*) *Gabbro-gneiss*, with the composition of gabbro.
(*e*) *Peridotite-gneiss*, with the composition of peridotite.
(*f*) *Conglomerate-gneiss*, of conglomerate texture, usually with the composition of granite.

SCHISTS.—The schists are fine-grained, schistose rocks, the compositions of which are unlike those of any igneous rock. Some of them may have been derived from igneous rocks; but if so, their compositions have been so changed by metamorphism that

their origin is extremely obscure. Most of them were originally fragmental rocks. The schists split into thin slabs which break apart, leaving fairly smooth surfaces. They are named in accordance with their prominent mineral component.

(*a*) *Mica schist*, composed of mica and quartz.

(*b*) *Hornblende schist*, composed of hornblende and quartz.

(*c*) *Talc schist*, composed of talc, predominately.

(*d*) *Chlorite schist*, composed mainly of chlorite.

(*e*) *Slate*, of many minerals, very fine-grained.

MARBLES.—Marbles are crystalline rocks composed mainly of calcite or dolomite. Originally, they were fragmental limestones, but by solution and deposition they have in most instances lost their fragmental characters. Some marbles are distinctly schistose, but others are apparently massive. Their components are so easily dissolved and redeposited under changing conditions of pressure and temperature that the schistose structure, if ever present, was in many cases subsequently obliterated.

B. FRAGMENTAL ROCKS

Fragmental or clastic rocks are composed of fragments of minerals, of animal or vegetable matter, of other rocks or of mixture of minerals, rocks and organic matter. Their materials are the waste of bodies which formerly existed in some other place.

These materials have been brought together mainly by some transporting agency, such as water, ice in the form of glaciers, or the air.

A small portion of waste may remain on the sur-

face where it was formed, or may be transported short distances by the aid of gravity, forming *terrestrial deposits* as distinguished from *sedimentary deposits*. Other waste material may be transported from one portion of the surface to another by the wind. This is assorted by the wind during its transit and is finally deposited in layers. The deposits thus formed are terrestrial in the sense that they are laid down on the land, but are sedimentary, since they are precipi-

FIG. 102.—Stratified Sandstone.

tated from the air. They are known as *sub-aërial deposits*.

Material dropped from water or the air is sorted and deposited in layers. That left by glacial ice may be unsorted and indiscriminately heaped. The former is *stratified* (Fig. 102). Its origin is *sedimentary*. Deposits left by the ice are principally scattered bowlders and masses of clay and bowlders, known as *till*, which, when consolidated, is sometimes difficult to distinguish from water-deposited sediments.

The waste that accumulates in the fragmental

sediments may result from the action of (1) water in the form of frost, rain, rivers, lakes and seas, or from that of (2) volcanoes during explosive eruptions. To these may be added as a third (3) class the terrestrial deposits. The material of fragmental rocks may be *aqueo-clastic* or *pyro-clastic*.

Aqueo-clastic Rocks.—The aqueo-clastic rocks consist of deposits of the hard parts of animals and plants that lived in water and of waste produced by the breaking down of rocks by various agencies. The remains of land animals and plants may be washed into water and deposited with other materials. Consolidation ensues as the result of pressure and of processes of cementation. Rocks of this class may be separated into those composed of material of (1) inorganic origin, and those composed of (2) organic material. Most rocks of the latter kind contain also much inorganic material.

Inorganic Aqueo-clastic Rocks.—Inorganic aqueo-clastic rocks are best classified on the basis of texture, since they are all made of the waste of pre-existing rocks, and, therefore, are composed of similar material. Beginning with the finest deposits we may distinguish:

(*a*) *Silt*, composed of mud, or the finest portions of worn-down rocks.

(*b*) *Shale*, a consolidated silt with the addition of a little cementing material.

(*c*) *Sand*, fragments of minerals, mainly quartz.

(*d*) *Sandstone*, a sand cemented by the infiltration of various substances.

(1) *Arkose*, in which there are many feldspar grains, in addition to quartz.

(2) *Graywacke*, in which are many grains of minerals other than feldspar and quartz. Color gray or greenish.
(3) *Calcareous sandstone*, in which the cement is calcite or dolomite.
(4) *Argillaceous sandstone*, in which the cement is mainly clay.
(5) *Ferruginous sandstone*, in which the cement is limonite or some other iron compound.
(6) *Quartzite*, in which the cement is quartz.

FIG. 103.—Conglomerate Pebbles of Different Kinds in Sand Cement.

(*e*) *Shingle*, pebbles and small rounded pieces of rock.
(*f*) *Conglomerate*, shingle cemented by finer-grained material (Fig. 103).
(*g*) *Breccia*, composed of sharp-edged fragments of rocks and minerals (Fig. 104).
Grit, in which the fragments are quartz, uniformly small.

Organic Aqueo-clastic Rocks.—The organic aqueo-clastic rocks are separable according to composition as follows:

(A) CALCAREOUS, composed of carbonates.

(*a*) *Limestone*, mainly $CaCO_3$.

Shell limestone, fragments of shells.
Coral limestone, fragments of corals.
Chalk, fragments of tests of infusoria.
Marl, chalky material mixed with clay, fragments of shells, etc.

(*b*) *Dolomite*, mainly $(Mg,Ca)CO_3$.

FIG. 104.—Breccia. Chert Fragments in Sandy Matrix.

(B) CARBONACEOUS, composed of carbon, hydrocarbons, etc.

(*a*) *Coal*, altered plant remains.

(C) PHOSPHATIC, composed mainly of $Ca_4(CaCl)(PO_4)_3$.

(*a*) *Bone-breccia*, fragments of bones.

(*b*) *Glauconite*, small mollusk shells, filled with green phosphatic clay, mud and glauconite.

(D) SILICEOUS, composed mainly of SiO_2.

(*a*) *Infusorial earth*, tests of microscopic animals and plants.

(*b*) *Flint*, compact chalcedony, quartz and opal, in nodules.

(E) FERRUGINOUS, composed mainly of limonite or hematite.

(*a*) *Fossiliferous iron ore*, fragments of shells and other parts of organisms.

Pyro-clastic Rocks.—The pyro-clastic rocks are composed of material that is blown from volcanoes and which falls near the crater or is wafted by the wind to distant points. That which falls into water becomes stratified. That which falls on land is rudely sorted but is not distinctly stratified. The coarsest material accumulates near the volcano, and the finest at the greatest distance from the center of eruption.

The pyro-clastic deposits may be classified according to coarseness into:

(*a*) *Volcanic breccia*, or *agglomerate*.

(*b*) *Tuff*.

(*c*) *Lapilli*.

(*d*) *Volcanic sand*.

Terrestrial Deposits.—The terrestrial deposits are placed here merely for convenience. They consist of fragmental materials which are left where formed, or which have been transported from one portion of the dry land surface to another. Their original material may have been of aqueo-clastic or of pyro-clastic origin, or it may have been produced by the disintegration of rocks through the chemical action of the atmosphere. Since the deposits are formed at the base of the atmosphere, they are sub-aërial.

Only three rocks are of sufficient importance to need mention here:

(*a*) *Geest*, the mantle of rock waste produced by decay of pre-existing rocks.
Soil, rock débris mixed with organic matter.

(*b*) *Loess*, very fine clay-like compacted dust, probably wind-blown.

(*c*) *Sandstone*, consolidated wind-blown sand.

OTHER ROCKS

There are other rocks essentially different from all of those mentioned above; such, for instance, as the *dike rocks* referred to on a previous page, those produced by the chemical decomposition of other rocks, e.g., *clay* (p. 102) and *serpentine* (p. 100), and those produced by metamorphic action around the borders of great igneous intrusions. They are not included in this classification, however, because they are of local, rather than of widespread, occurrence.

II

KEY TO THE DETERMINATION OF ROCKS (EXCEPT COAL)

FOR the accurate determination of rocks, their field relations must be studied, and, in many cases, their sections must be examined under the microscope. The recognition of the true nature of hand specimens is often extremely difficult. Frequently, they can be determined only approximately.

The following key is arranged to guide the users to the discussions of the rock types referred to in the text. It takes account only of the most important rocks and only of those types which are developed with characteristic features. A key for the determination of *all* rock types would be too complicated for use by anyone but a specialist in lithology, and would demand the aid of a microscope. Rocks without well-defined features, however, cannot be determined by any "key." They must be studied in the field and under the microscope.

I. Very Coarse-grained.

A. FRAGMENTAL. Consists of fragments of minerals, rocks or organisms, in a fine-grained matrix.

1. Fragments of rocks and minerals, rounded and pebble-like.—Conglomerate, and Grit (p. 203).

2. Fragments sharp-edged. Breccia (p. 203).
   (*a*) Fragments composed of igneous material. Cement is lava or tuff.—Agglomerate (p. 205).
3. Fragments consist of pieces of shells, coral or other calcareous portions of organisms.—Limestone (p. 204).
4. Fragments consist of bones, teeth, etc. —Bone breccia (p. 204).

B. CRYSTALLINE. Contains no fragments. Not composed of transported material.—Pegmatite (p. 113).

Pegmatites are named in accord with their mineral composition (see p. 197), thus: granite-pegmatite, gabbro-pegmatite, etc.

II. Medium to fine-grained.—Components small, but distinctly visible to unaided eye.

A. FRAGMENTAL. Composed of little spheres, sand grains, volcanic ash, particles of organisms, or other materials. Often stratified.

1. Composed of limonite or hematite.
   (*a*) Cellular limonite.—Bog iron ore (p. 193).
   (*b*) Grains round, like constituents of fish-roe. — Ferruginous oölite (p. 193).
   (*c*) Fragments of shells, corals, etc.— Fossiliferous iron ore (p. 205).
2. Composed of fragments of shells, or of other calcareous materials.
   (*a*) Effervesces in cold HCl.

(1) Composed of fragments of organisms. — Limestone (p. 204).

(2) Composed of round grains. —Oölite (p. 192).

(3) Finely granular.—Chalk (p. 204), or Marl (p. 204).

(*b*) Does not effervesce in cold HCl except when in finest powder. —Dolomitic limestone (p. 204).

3. Composed principally of sand grains.—Sandstone (p. 202).

(*a*) Sand nearly all quartz.

(1) Cement is quartz.—Quartzite (p. 203).

(2) Cement is calcite or dolomite.—Calcareous sandstone (p. 203).

(3) Cement is clayey.—Argillaceous sandstone (p. 203).

(4) Cement is limonite or other iron compound.—Ferruginous sandstone (p. 203).

(*b*) Many of the sand grains are feldspar.—Arkose (p. 202).

(*c*) Sand very impure: contains shreds of hornblende, augite, chlorite, etc. Rock gray or dark greenish-gray.—Graywacke (p. 203).

(*d*) Sand much mixed with clay. Stratified. Chips easily to

flakes.—Arenaceous, or sandy, shale (p. 202).

4. Composed of particles of lava, ashes, cinders, etc.—Tuff (p. 205).
5. Composed of fine powder that scratches glass.—Siliceous sinter and infusorial earth (p. 205).
6. Composed of fine dust, often mixed with clay.—Loess (p. 206).

B. CRYSTALLINE. Components formed in place. Not transported.

1. Composed of a single mineral.
   (*a*) Soluble in water.
      (1) Salty taste. — Rock Salt (p. 192).
   (*b*) Not soluble in water.
      (1) Soluble in cold or hot HCl with effervescence.— Limestone (pp. 192, 204).
         (*a*) Fibrous, radiate.—Stalactite (p. 192).
         (*b*) Banded. Translucent.—Mexican onyx (p. 192).
         (*c*) Not banded. Granular.—Marble (p. 200).
         (*d*) Porous, tubular.—Travertine (p. 192).
      (2) Soluble in hot HCl without effervescence.
         (*a*) Soft. Gives sulphur test on charcoal. Gypsum (p. 192).
         (*b*) Red or yellow, ferrugi-

nous.—Bog iron ore (p. 193).

(3) Insoluble in acids. Soft. Rock usually gray.—Soapstone (p. 101).

(4) Insoluble in acids. Powder scratches glass.—Siliceous sinter (p. 192).

2. Composed of several distinct minerals.

(A) Massive. Components equidimensional.

(1) Granular. Components of approximately equal sizes.

(*a*) Containing quartz.

1. Containing much orthoclase.—Granite (p. 197).

(*b*) Containing no quartz, or only a small quantity, but some orthoclase.

1. Containing orthoclase, but very little, if any, plagioclase.—Syenite (p. 197).

2. Containing orthoclase and plagioclase.—Monzonite (p. 197).

(*c*) Containing no quartz and no orthoclase.

1. Containing plagio-

clase and hornblende. Rock light or dark gray.—Diorite (p. 197).

2. Containing plagioclase and augite. Rock darker and heavier than diorite.—Gabbro (p. 197).

(*d*) Containing no feldspar.

1. Composed of hornblende, augite, or olivine, or of mixtures of these.—Peridotite (p. 197).

(2) Porphyritic.—Some constituents larger than others and usually with crystal outlines. Often amygdaloidal.

(*a*) Containing quartz in phenocrysts.

1. Matrix feldspathic.—Rhyolite (p. 197).

(*b*) Containing no quartz in phenocrysts.

1. Phenocrysts mainly of orthoclase, rarely of plagio-

clase.—Trachyte (p. 197).

2. Phenocrysts of orthoclase and plagioclase.—Latite (p. 197).

(*c*) No phenocrysts of orthoclase.

1. Phenocrysts of plagioclase and hornblende.—Andesite (p. 197).

2. Phenocrysts of plagioclase and augite.—Basalt (p. 197).

(*d*) No feldspar phenocrysts.

1. Phenocrysts of hornblende, augite, or olivine. — Basalt or Limburgite (p. 197).

3. Composed of several minerals, but so fine-grained that the individual components cannot be identified.

(*a*) Light-colored.—Felsite (p. 197).

(*b*) Dark-colored.—Basalt (p. 197).

(B) Schistose or foliated. Constituents elongated in parallel directions. Rock often banded in same direction. Splits more easily parallel to schistosity than across it.

(1) Containing feldspar.—Gneisses (p. 199). The gneisses are named in accordance with their mineral composition, as in the case of massive rocks, thus: granite-gneiss, gabbro-gneiss, etc.

(2) Containing no feldspar, or only a little.—Schists (p. 199).

(*a*) Abundant mica, usually also quartz. Mica flakes can be pried off by knife blade.—Mica schist (p. 200).

Light colored.—Muscovite schist (p. 200).

Dark colored.—Biotite schist (p. 200).

(*b*) Abundant hornblende, usually also quartz. Hornblende fragments can be pried off by knife blade. Rock usually black and glistening. — Hornblende schist (p. 200).

(*c*) Abundant talc, usually also quartz. Soft, greasy feel. Rock white, gray, light green. — Talc schist (p. 200).

(*d*) Abundant chlorite, usually also quartz. Soft, lustrous. Rock green, dark green to almost b l a c k . — Chlorite schist(p. 200).

(*e*) A l m o s t exclusively quartz, with very little mica, or other flaky component. — Quartz schist (p. 200).

III. Dense.—Individual grains not visible to unaided eye.

A. Glassy, with or without pores.

1. Full of cavities and pores.

(*a*) Cavities minute, numerous and coalescing. Structure frothy.—Pumice (p. 195).

(*b*) Cavities larger, few and separate and partly or entirely filled with mineral matter.—Amygdaloid (p. 196). N.B.—This is a structure name. The character of the rock exhibiting the structure should be determined.

2. No pores, or only an occasional one.

(*a*) Rock has brilliant luster.—Obsidian (p. 193).

(*b*) Rock has dull luster.—Pitchstone (p. 193).

$(a)_1$ and $(b)_1$. Containing little quartz grains. —Quartz-porphyry (p. 195).

$(a)_2$ and $(b)_2$. Containing little feldspar grains. — Trachyte or Andesite (p. 197).

$(a)_3$ and $(b)_3$. Containing little hornblende, augite, or olivine grains. — Basalt or Limburgite (p. 197).

B. Lithoidal or Stony. Dull. Extremely fine granular.

1. Very hard. Scratches steel.
   (*a*) Black, gray, or white. Smooth fracture. Nodules or thin layers in chalk or limestone.—Flint (p. 205).
   (*b*) Dark gray, yellow. Porous. Rough fracture.—Chert (p. 192).
   (*c*) White or light-colored. Granular fracture.—Quartzite (p. 203).
2. Hard. Is scratched by steel, but not by finger-nail.
   (*a*) Effervesces when powder is moistened with HCl.
      (1) Small fragments dissolve completely or nearly completely when treated with cold acid.—Limestone (pp. 192, 204).
      (2) Small fragments dissolve very slowly in cold HCl, but rapidly in hot acid —Dolomite (pp. 192, 204).
      (3) Powder partly dissolved, but

leaves clayey residue when treated with acid.—Calcareous shale p. 202.

(*b*) Does not effervesce with hot HCl, even in powder.

(1. Stratified. Usually breaks into chips parallel to bedding.

(*a*. Clayey odor when breathed on.—Shale (p. 202).

(*a*)1 Gives Phosphorus reaction.—Phosphate rock (p. 204).

(2) Schistose. Splits with smooth fracture into plates, usually across bedding. Frequently rings when struck by steel.

(*a*) Rock generally homogeneous.—Slate (p. 200).

(3) Massive.

(*a*) Black.—Basalt, or Limburgite (p. 197).

(*b*) White, light gray, red, purple, rarely green.—Felsite (p. 197).

(*c*) Pale to dark green, often crossed by veins of white or light green talc or calcite. Translucent. Waxy luster. Soluble in hot HCl leaving residue of gelatinous silica. Serpentine (pp. 100, 206).

3. Very soft. Scratched by finger-nail.
   (*a*) When rubbed between the fingers, feels smooth and greasy.
      (1) Has clayey odor. — Clay (pp. 102, 206).
   (*b*) When rubbed between fingers it crumbles to powder.
      (1) Effervesces briskly with HCl.
         (*a*) Porous, tubular.—Calc sinter or travertine (p. 192).
         (*b*) Finely-granular.—Chalk (p. 204) or Marl (p. 204).
         (*c*) Neither (*a*) nor (*b*). Compacted dust.—Loess (p. 206).
      (2) Does not effervesce briskly with HCl.
         (*a*) Powder scratches glass.—Siliceous sinter and infusorial earth (pp. 192, 205).
         (*b*) Gives sulphur reaction.—Gypsum (p. 192).
         (*c*) Neither (*a*) nor (*b*). Compacted dust.—Loess (p. 206).

INDEX

Achroite, 104
Acid potassium sulphate, 131, 147, 148.
Actinolite, 110, 177, 182, 183
Adularia, 115
Agate, 34
Agglomerate, 205
Alabaster, 66
Albite, 116, 181, 184
Alkalies, 144–146
Almandite, 85, 183
Alum, 64
Alumina, 147
Aluminates, 46–49
Aluminium, 44, 45, 64, 181
Aluminium, reactions of, 151
Alunite, 64, 177, 179, 181, 184, 185
Amber mica, 93, 94
Amethyst, 34
Amorphous rocks, 193
Amphiboles, 109–112
Amygdaloidal rocks, 196
Analcite, 124, 178, 179, 184
Andalusite, 87, 177, 179, 181
Andesine, 116
Andesite, 195, 197
Andradite, 85, 182, 183
Anglesite, 63, 176, 177, 178, 179, 183
Anhydrite, 60, 61, 175, 178, 182
Ankerite, 175, 178, 179
Anorthite, 116, 181, 182
Antimony, 12, 13, 172, 181
  reactions of, 136, 138, 151
Apatite, 70, 71, 175, 176, 178, 179, 182, 184
Aphanitic rocks, 194
Apophyllite, 120, 121, 177, 178, 179, 182, 184, 185
Apparatus for mineral tests, 129, 130
Aquamarine, 100
Aqueo-clastic rocks, 202–205
Aragonite, 56, 57, 176, 177, 178, 179, 182
Argentite, 184
Argillaceous sandstone, 203
Arkose, 202
Arsenates, 70–77
Arsenic, 24, 181
  reactions of, 136, 138, 151, 152
Arsenides, 22–25
Arsenopyrite, 24, 170, 181, 183, 184
Asbestus, 100, 111, 180, 182, 183
Atacamite, 175, 182, 185
Augite, 108, 172, 175, 177, 181, 182, 183
Azurite, 59, 60, 175, 182, 185

Balas ruby, 47
Barite, 15, 16, 61, 62, 176, 178, 179, 181
Barium, 58, 181
  reactions of, 145, 152
Barium salts, 62
Basalt, 195, 196, 197
Basaltic hornblende, 111

Bauxite, 44, 45, 173, 174, 179, 181, 185
Beads, use of, 140–142
Beryl, 99, 177–181
Beryllium, 181
Biotite, 93, 172, 175, 176, 183, 184, 185
Bismuth, reactions of, 139, 152
Black lead, 9
Blende, 15, 16
Bloodstone, 34
Blowpipe, 128, 131–134
Blue beryl, 100
Blue litmus paper, 131
Bog ore, 46, 193
Bone-breccia, 204
Borates, 31–33
Borax, 31–33, 131, 181, 184, 185
Bornite, 10, 21, 22, 170, 182, 183
Boron, 181
  reactions of, 152, 153
Bort, 8
Brazilian emerald, 104
Brazilian sapphire, 104
Breccia, 203, 204, 205
Brittle micas, 95, 181, 183, 185
Bromides, 148
Bromines, reactions of, 153
Bronzite, 106, 107, 177, 183
Brookite, 40, 171–176, 184
Brown clay ironstone, 46
Brown hematite, 45, 46
Brucite, 43, 176–179, 183, 185
Bucklandite, 90
Bunsen burner, 129
Bytownite, 116

Cadmium, reactions of, 139, 153, 154
Cairngorm, 34
Calamine, 102, 176, 178, 179, 185
Calcareous rocks, 204
  sandstone, 203
Calcite, 6, 10, 15, 50–52, 106, 175–179, 182, 192
Calcium, 182
  reactions of, 145, 154
Californite, 105
Carbon, 182
Carbonaceous rocks, 204
Carbonado, 8
Carbonates, 49–60, 182
  reactions of, 149, 150
Carnallite, 177
Carnelian, 34
Carnotite, 80, 81, 174, 182, 184, 185
Cassiterite, 40, 41, 71, 89, 95, 171–176, 178, 184
Celestite, 62, 63, 178, 179, 184
Cerargyrite, 27, 28, 176–177, 179, 182, 184
Cerium, 78
Cerussite, 58, 59, 175, 177, 179, 183
Ceylonite, 47
Chabazite, 123, 124, 176–179, 182, 184
Chalcedony, 34
Chalcocite, 16, 170, 182
Chalcopyrite, 10, 16, 21, 25, 170, 182, 183
Chalk, 51, 204
Charcoal in mineral tests, 130, 136–140
Chert, 192
Chiastolite, 88
Chile saltpeter, 31
Chlorates, 147
Chlorides, 27–30
  reactions of, 148
Chlorine, 182
  reactions of, 154
Chlorite-schist, 200
Chlorites, 96, 97, 175, 176, 183, 185

Chloritoid, 96, 175, 177
Chromates, 66–70
Chrome-iron alloy, 48
Chromite, 48, 171, 173, 182, 183
Chromium, 48, 182
  reactions of, 141, 146, 149, 154, 155
Chrysocolla, 119, 120, 173, 175, 176, 178, 182, 185
Chrysoprase, 34
Chrysotile, 100, 176, 177, 179, 183, 185
Cinnabar, 17, 170, 172–174, 183
Citrine, 34
Clay, 101, 102
  ironstone, 39
Cleavage, 6
Clinochlor, 96
Clintonite, 176
Closed tube, use of, 134, 135
Coal, 204
Cobalt, 23, 76, 182
  reactions of, 138, 141, 155
  nitrate, 131, 147
Cobaltite, 23, 24, 170, 181, 182, 184
Colemanite, 31–33, 179, 181, 182, 185
Color, changes of, 135
Coloration of flame, 142–146
Columbates, 77–79
Columbite, 77, 78, 170, 171, 182, 183
Columbium, 182
  reactions of, 141, 149, 155
Conglomerate, 199, 203
Copper, 9, 16, 21, 22, 26, 59, 62, 82, 120, 170, 182
  reactions of, 138, 141, 146, 155
  oxide, 131
Coral, 204
Corundum, 36–38, 170, 171, 173, 176–181
Covellite, 16–18, 170, 182
Crocidolite, 175
Crocoite, 69, 70, 174, 182, 183
Crystalline rocks, 190–200, 208, 210
Crystallization, 3
Cuprite, 35, 36, 59, 170–174, 182
Cyanite, 98, 181
Cyprine, 106, 182

Decrepitation, 137
Deflagration, 137
Density, 5
Diallage, 108
Diamond, 7, 8, 175, 176, 180, 182
Didymium, 141
Diorite, 197, 199
Disthene, 98
Dolomite, 52, 53, 175, 176, 177, 178, 179, 182, 183, 192, 204
Dry-bone ore, 54, 55

Edenite, 111
Elements, 7–12
Emerald, 100
Emery, 37
Endlichite, 73
Enstatite, 106, 176, 177, 178, 180, 183
Epidote, 89, 90, 175–178, 182, 185
Erbium, 78
Erythrite, 24, 75, 174, 181, 182, 185

Fassaite, 108
Fayalite, 83, 183
Feldspars, 112–119, 194
Felsitic rocks, 194
Ferberite, 68, 173
Ferrites, 46–49
Ferruginous oölite, 193
Ferruginous rocks, 205
Ferruginous sandstone, 203
Fertilizers, mineral, 61, 66, 71

Fire opal, 43
Flame, blowpipe, 131
  Bunsen, 129
Flame coloration, 142–146
Flint, 35, 205
Fluorides, 27–30
  reactions of, 148
Fluorine, 29, 182
  reactions of, 155, 156
Fluorite, 15, 16, 29, 30, 67, 175, 176, 177, 178, 179, 182
Fluospar, 29, 30
Forsterite, 83
Fossil ore, 39, 205
Fowlerite, 177
Fragmental rocks, 196, 200–206, 207 208
Franklinite, 48, 84, 170, 171, 183, 185
Fusibility, 136, 137

Gabbro, 197, 199
Galena, 15, 16, 22, 55, 58, 59, 63, 170, 183
Garnet, 85, 86, 106, 172, 175-178, 180, 181, 183
Geest, 206
Gem stones, 7, 8, 34, 37, 43, 47, 67, 76, 77, 84–89, 99–100, 103–106, 109, 119
Glass in mineral tests, 130
Glassy rocks, 193, 215
Glauconite, 175, 176, 204
Glaucophane, 112, 175, 179, 181, 183, 184
Gneiss, 198, 199
Goethite, 45, 173, 183, 185
Gold, 11, 12, 182
  reactions of, 138, 156, 157
Golden beryl, 100
" Gossan," 20
Granite, 194, 197, 199
Granitoid rocks, 194
Graphite, 8, 9, 170, 172, 173, 182
Graywacke, 203
Grossularite, 85, 182
Gypsite, 66
Gypsum, 9, 33, 57, 61, 64–66, 175–179, 182, 185, 192

Halite, 28, 29, 66, 175–179, 182, 184, 192
Hardness, Moh's scale of, 4
Harmotome, 122, 176, 178, 179, 181, 184
Heat, sources of, 129, 130
Heavy spar, 61, 62
Heliotrope, 34
Hematite, 38, 39, 170, 171, 173, 174, 183, 193
Heulandite, 182
Hessonite, 85
Hiddenite, 109
Horn silver, 27, 28
Hornblende, 111, 112, 171–173, 175, 176, 177, 181–183, 200
Huebnerite, 68, 171, 172, 173, 174, 175, 176, 178
Hyacinth, 87
Hyalite, 43
Hydrated silicates, 119–121
Hydrochloric acid, 131, 148–150
Hydrofluoric acid, 135
Hydrogen sulphide, 134
Hydroxides, 42–46
Hypersthene, 107, 172, 175, 177, 183

Ice, 192
Iceland spar, 51
Ilmenite, 126, 127, 170, 171, 183, 184
Indicolite, 104
Indigo copper, 17
Infusorial earth, 43, 205
Intrusive rocks, 196

Iodides, 145
Iodine, reactions of, 155
Iron, 21, 38, 41, 48, 54, 59, 182, 183
  reactions of, 138, 141, 155, 159
Iron pyrites, 18
Iron sulphides, 18

Jasper, 35

Kaolinite, 101, 102, 176, 177, 179, 181, 185
Key for rocks, 207–218
  to minerals, 170–180
Kunzite, 109
Kyanite, 98, 179, 181

Labradorite, 116, 175, 177
Land plaster, 61, 66
Lapilli, 205
Latite, 197
Laumontite, 123, 176, 177, 178, 179, 182
Lead, 9, 13, 14, 25, 58, 59, 62–64, 72, 82, 102, 183
  reactions of, 139, 158
Lepidolite, 95, 105, 177, 179, 182–185
Lepidomelane, 93
Leucite, 97, 180, 181, 184
Limburgite, 197
Lime, 52
Limestone, 51, 61, 64, 66, 192, 193, 204
Limonite, 20, 45, 59, 171, 172, 174, 183, 185, 193
Lithium, 183
  reactions of, 145, 158
  salts, 95
Lithoidal rocks, 216–218
Loess, 206
Luster, 3, 4

Magnesia, 53
Magnesian limestone, 52
Magnesite, 52, 53, 175–177, 179, 183
Magnesium, 183
  reactions of, 146, 159
Magnesium ribbon, 137, 149
Magnetic pyrites, 18
Magnetite, 45, 48, 71, 179, 183
Malachite, 59, 60, 175, 182, 185
Manganese-spatite, 71
Manganese, 56, 183
  reactions of, 141, 146, 159, 160
Marbles, 200
Marcasite, 18, 19, 170, 183, 184
Marl, 204
Massive rocks, 193–197, 211, 212, 213, 217
Melanite, 85
Mercury, 13, 17, 183
  reactions of, 136, 160
Metamorphic rocks, 197–200
Mexican onyx, 51, 192
Mica, 92–97, 181, 200
Microcline, 115, 116, 177, 180, 181, 184
Microcosmic salt, 131
Milky quartz, 34
Mimetite, 72, 176, 177, 179, 181, 182, 183
Mineral fertilizers, 61, 66, 71
Mineral tests, apparatus for, 129, 130
Minerals, composition of, 2
  key to, 170–180
  reactions of, 151–167
Mispickel, 24
Moh's scale of hardness, 4
Molybdates, 66–70
Molybdenite, 13, 14, 67, 170, 172, 183
Molybdenum, 13, 69, 183
  reactions of, 138, 139, 141, 149, 160
Monzonite, 197

Moonstone, 115
Muscovite, 94, 95, 176, 177, 179, 184, 185

Natrolite, 124, 178, 179, 184
Nephelite, 91, 177, 178, 179, 181, 184
Niccolite, 23, 170, 181, 183
Nickel, 23, 183
  reactions of, 138, 160, 161
Niter, 31, 131, 179, 184
Nitrates, 31, 183
  reactions of, 147
Nitric acid, reactions of, 161
Nitrites, reactions of, 147
Nitrogen, 183
Nitrogen peroxide, 135
" Norite," 20

Obsidian, 193
Ocher, 39
Octahedrite, 40, 175, 176, 184
Oligoclase, 116, 118
Olivine, 83, 84, 176, 177, 178, 183
Onyx, 34
Oölite, 192
Oölitic ore, 39
Opal, 42, 43, 177, 178, 179, 180, 184, 185
Open tube, use of, 135, 136
Oriental amethyst, 37
Oriental emerald, 37
Oriental topaz, 37
Orthoclase, 113–115, 177, 178, 180, 181, 184
Oxides, 33–42
Oxygen, reactions of, 161

Paragonite, 95, 179
Pegmatite, 113
Pentlandite, 20
Peridot, 84
  of Ceylon, 104
Peridotite, 197, 199
Perthite, 115
Phenocrysts, 194
Phillipsite, 122, 178, 179, 182, 184
Phlogopite, 93, 176–179, 183–185
Phosphates, 70–77
Phosphatic rocks, 204
Phosphoric acid, reactions of, 161, 162
Phosphorite, 71
Phosphorus, 149, 184
Physical properties of minerals, 2–6
Picotite, 47
Pigments, 15, 16, 19, 24, 42, 46, 57, 62, 74
Pitchblende, 81, 82
Pitchstone, 193
Plagioclase, 116–119, 180
Plasma, 34
Plaster of Paris, 65, 66
Platinum in mineral tests, 130, 172
Plumbago, 9
Plutonic rocks, 196
Porphyritic rocks, 194
Potash, 97
Potassium, 29, 64, 145, 184
Precious opal, 43
Prochlorite, 96
Proustite, 25, 26, 170, 174, 181, 184
Psilomelane, 173, 181, 183–185
Pumice, 195
Pyrargyrite, 25, 26, 170, 174, 181, 184
Pyrite, 11, 18–20, 25, 170, 183, 184
Pyro-clastic rocks, 205, 206
Pyrolusite, 41, 42, 170, 183
Pyromorphite, 71, 72, 174, 175, 176, 177, 179, 182–184
Pyrope, 85, 183
Pyroxenes, 106–109
Pyrrhotite, 18, 20, 170, 183, 184

Quartz, 11, 15, 33–35, 106, 175–176, 178–180, 184
Quartz phorphyry, 195
Quartzite, 203

Radium, 79, 80, 81, 82
Reactions of minerals, 151–167
Reagents, 131
Reduction, 137
Rhinestone, 34
Rhodochrosite, 55, 56, 176, 177, 178, 179, 183
Rhodonite, 177, 183
Rhyolite, 197
Rock crystal, 34
Rock-gypsum, 66
Rock salt, 61, 64, 192
Rocks, composition of, 1, 189, 190
  key for, 207–218
Rubellite, 95, 104
Ruby, 37
Ruby spinel, 47
Rutile, 39, 40, 171–177, 184

Salt, 28, 29
  of phosphorus, 131
Samarskite, 78, 79, 170, 171, 182
Sanadine, 115
Sand, 202
Sandstone, 201, 202, 203, 206, 209, 210
Sapphire, 37
Sardonyx, 35
Satin spar, 51, 66
Scheelite, 66, 67, 176, 178, 179, 182, 184
Schistose rocks, 197–200, 213, 214, 216, 217
Scolecite, 123, 179, 182
Selenite, 66
Selenium, reactions of, 136, 139, 162
Serpentine, 100, 101, 175, 176, 177, 178, 183, 185
Shale, 202
Shell, 204
Shiogle, 203
Siderite, 54, 171, 172, 173, 174, 179, 183
Silica, reactions of, 141
Silicates, 82–106, 184
Siliceous rocks, 204
Siliceous sinter, 43, 192
Silicon, 184
  reactions of, 162, 163
Silt, 202
Silver, 10, 11, 15, 16, 25–28, 62, 82, 172, 184
  reactions of, 138
Slate, 200
Smaltite, 23, 24, 170, 181, 182
Smithsonite, 54, 55, 176, 177, 178, 179, 185
Smoky quartz, 34
Soapstone, 101
Soda-niter, 31, 179, 184
Sodium, 184
  reactions of, 145
Sodium carbonate, 131
Sodium tungstate, 67
Soil, 206
Spectroscope, 143
Specular ore, 39
Spessartite, 85, 183
Sphalerite, 15, 16, 22, 25, 55, 171–176, 177, 178, 185
Sphene, 125, 126, 184
Spinel, 47, 171, 172, 175–179, 181, 183
Spodumene, 109, 181, 183
Stalactite, 51, 192
Staurolite, 90, 91, 170, 175, 176, 181, 183, 185
Steatite, 101, 183, 185
Stibnite, 12, 13, 170, 181

Wolframite, 67, 68, 170, 171, 173, 174, 183, 184
Wollastonite, 179
Wood tin, 41
Wulfenite, 68, 174, 176, 177, 178, 179, 183

Yellow ocher, 46
Yttrium, 78
Yttrotantalite, 78, 79, 175

Zeolites, 121–125, 181, 185
Zinc, 13, 15, 16, 36, 54, 55, 84, 85, 102, 185
  granulated, 131
  reactions of, 139, 147, 148, 167
Zincite, 36, 84, 171, 174, 185
Zircon, 86, 87, 176, 178, 180, 185
Zirconia, 87
Zirconium, 185
  reactions of, 167

AUG 2 1 1936

AUG 2 1 1936